ANNEX 2 Methodology and Data for Estimating CO_2 Emissions from Fossil Fuel Combustion

2.1. Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion

Carbon dioxide (CO_2) emissions from fossil fuel combustion were estimated using a "bottom-up" methodology characterized by nine steps. These steps are described below.

Step 1: Determine Total Fuel Consumption by Fuel Type and Sector

The bottom-up methodology used by the United States for estimating CO_2 emissions from fossil fuel combustion is conceptually similar to the approach recommended by the Intergovernmental Panel on Climate Change (IPCC) for countries that intend to develop detailed, sectoral-based emission estimates (IPCC/UNEP/OECD/IEA 1997). Adjusted consumption data are presented in Columns 2 through 8 of Table A-10 through Table A-25, with totals by fuel type in Column 8 and totals by end-use sector in the last rows. Fuel consumption data for the bottom-up approach were obtained directly from the Energy Information Administration (EIA) of the U.S. Department of Energy. These data were first gathered in physical units, and then converted to their energy equivalents (see "Energy Conversions" in Annex 6.5). The EIA data were collected through a variety of consumption surveys at the point of delivery or use and qualified with survey data on fuel production, imports, exports, and stock changes. Individual data elements were supplied by a variety of sources within EIA. Most information was taken from published reports, although some data were drawn from unpublished energy studies and databases maintained by EIA.

Energy consumption data were aggregated by sector (i.e., residential, commercial, industrial, transportation, electricity generation, and U.S. territories), primary fuel type (e.g., coal, natural gas, and petroleum), and secondary fuel type (e.g., motor gasoline, distillate fuel, etc.). The 2005 total adjusted energy consumption across all sectors, including territories, and energy types was 78,742.4 trillion British thermal units (TBtu), as indicated in the last entry of Column 8 in Table A-10. This total excludes fuel used for non-energy purposes and fuel consumed as international bunkers, both of which were deducted in earlier steps.

Electricity consumption information was allocated to each sector based on EIA's distribution of electricity retail sales to ultimate customers (i.e., residential, commercial, industrial, and other). Because the "other" fuel use includes sales to both the commercial and transportation sectors, EIA's limited transportation electricity use data were subtracted from "other" electricity use and also reported separately. This total was consequently combined with the commercial electricity data. Further information on these electricity end uses is described in EIA's *Annual Energy Review* (2006a).

There are also three basic differences between the consumption data presented in Table A-10 through Table A-25 and those recommended in the IPCC emission inventory methodology.

First, consumption data in the U.S. inventory are presented using higher heating values (HHV)[1] rather than the lower heating values (LHV)[2] reflected in the IPCC emission inventory methodology. This convention is followed because data obtained from EIA are based on HHV. Of note, however, is that EIA renewable energy statistics are often published using LHV. The difference between the two conventions relates to the treatment of the heat energy that is consumed in the process of evaporating the water contained in the fuel. The simplified

[1] Also referred to as Gross Calorific Values (GCV).

[2] Also referred to as Net Calorific Values (NCV).

convention used by the International Energy Agency for converting from HHV to LHV is to multiply the energy content by 0.95 for petroleum and coal and by 0.9 for natural gas.

Second, while EIA's energy use data for the United States includes only the 50 U.S. states and the District of Columbia, the data reported to the Framework Convention on Climate Change are to include energy consumption within territories. Therefore, consumption estimates for U.S. territories were added to domestic consumption of fossil fuels. Energy consumption data from U.S. territories are presented in Column 7 of Table A-10 through Table A-25. It is reported separately from domestic sectoral consumption, because it is collected separately by EIA with no sectoral disaggregation.

Third, there were a number of modifications made in this report that may cause consumption information herein to differ from figures given in the cited literature. These are (1) the reallocation of select amounts of coking coal, petroleum coke, natural gas, residual fuel oil, and other oil (>401F) for processes accounted for in the Industrial Processes chapter, (2) corrections for synthetic natural gas production, (3) corrections for ethanol added to motor gasoline, and (4) corrections for biogas in natural gas, (5) subtraction of other fuels used for non-energy purposes, and (6) subtraction of international bunker fuels. These adjustments are described in the following steps.

Step 2: Subtract uses accounted for in the Industrial Processes chapter.

Portions of the fuel consumption data for six fuel categories—coking coal, industrial other coal, petroleum coke, natural gas, residual fuel oil, and other oil (>401 F)—were reallocated to the Industrial Processes chapter, as these portions were consumed as raw materials during non-energy related industrial processes. Emissions from these fuels used as raw materials are presented in the Industrial Processes chapter, and is removed from the energy and non-energy consumption estimates within the Energy chapter.

- Coking coal, also called "coal coke," is used as a raw material (specifically as a reducing agent) in the blast furnace process to produce iron and steel, lead, and zinc and therefore is not used as a fuel for this process.
- Similarly, petroleum coke is used in multiple processes as a raw material, and is thus not used as a fuel in those applications. The processes in which petroleum coke is used include (1) ferroalloy production, (2) aluminum production (for the production of C anodes and cathodes), (3) titanium dioxide production (in the chloride process), (4) ammonia production, and (5) silicon carbide.
- Natural gas consumption is used for the production of ammonia, and blast furnace and coke oven gas used in iron and steel production.
- Residual fuel oil and other oil (>401F) are both used in the production of C black.

Step 3: Adjust for Biofuels and Conversion of Fossil Fuels

First, a portion of industrial "other" coal that is accounted for in EIA coal combustion statistics is actually used to make "synthetic natural gas" via coal gasification at the Dakota Gasification Plant, a synthetic natural gas plant. The plant produces synthetic natural gas and byproduct CO_2. The synthetic natural gas enters the natural gas distribution system. Since October 2000, a portion of the CO_2 produced by the coal gasification plant has been exported to Canada by pipeline. The remainder of the CO_2 byproduct from the plant is released to the atmosphere. The energy in this synthetic natural gas enters the natural gas distribution stream, and is accounted for in EIA natural gas combustion statistics. Because this energy of the synthetic natural gas is already accounted for as natural gas combustion, this amount of energy is deducted from the industrial coal consumption statistics to avoid double counting. The exported CO_2 is not emitted to the atmosphere in the United States, and therefore the energy used to produce this amount of CO_2 is subtracted from industrial other coal.

Second, ethanol has been added to the motor gasoline stream for several years, but prior to 1993 this addition was not captured in EIA motor gasoline statistics. Starting in 1993, ethanol was included in gasoline statistics. However, because ethanol is a biofuel, which is assumed to result in no net CO_2 emissions, the amount of ethanol added is subtracted from total gasoline consumption. Thus, motor gasoline consumption statistics given in this report may be slightly lower than in EIA sources.

Third, EIA natural gas consumption statistics include "biomass gas," which is upgraded landfill methane that is sold to pipelines. However, because this gas is biogenic, the biomass gas total is deducted from natural gas consumption. The subtraction is done only from natural gas in the industrial sector, as opposed to all end-sectors, because the biogas amount is small. Due to this adjustment—and the ammonia adjustment mentioned previously—industrial natural gas consumption in this report is slightly lower than in EIA sources.

Step 4: Subtract Consumption for Non-Energy Use

U.S. aggregate energy statistics include consumption of fossil fuels for non-energy purposes. Depending on the end-use, non-energy uses of fossil fuels can result in long term storage of some or all of the C contained in the fuel. For example, asphalt made from petroleum can sequester up to 100 percent of the C contained in the petroleum feedstock for extended periods of time. Other non-energy fossil fuel products, such as lubricants or plastics also store C, but can lose or emit some of this C when they are used and/or burned as waste.[3] As the emission pathways of C used for non-energy purposes are vastly different than fuel combustion, these emissions are estimated separately in the Carbon Emitted in Products from Non-Energy Uses of Fossil Fuels section in this chapter. Therefore, the amount of fuels used for non-energy purposes, shown in Table A-26, was subtracted from total fuel consumption.

Step 5: Subtract Consumption of International Bunker Fuels

Emissions from international transport activities, or international bunker fuel consumption, are not included in national totals, as required by the IPCC (IPCC/UNEP/OECD/IEA 1997). There is currently disagreement internationally as to how these emissions should be allocated, and until this issue is resolved, countries are asked to report them separately. EIA energy statistics, however, include these bunker fuels—jet fuel for aircraft, and distillate fuel oil and residual fuel oil for marine shipping—as part of fuel consumption by the transportation end-use sector. Therefore, the amount of consumption for international bunker fuels was estimated and subtracted from total fuel consumption (see Table A-27). Emissions from international bunker fuels have been estimated separately and not included in national totals.[4]

Step 6: Determine the C Content of All Fuels

The C content of combusted fossil fuels was estimated by multiplying adjusted energy consumption (Columns 2 through 8 of Table A-10 through Table A-25) by fuel-specific C content coefficients (see Table A-28 and Table A-29) that reflect the amount of C per unit of energy in each fuel. The C content coefficients used in the U.S. inventory were derived by EIA from detailed fuel information and are similar to the C content coefficients contained in the IPCC's default methodology (IPCC/UNEP/OECD/IEA 1997), with modifications reflecting fuel qualities specific to the United States.

Step 7: Estimate CO_2 Emissions

Actual CO_2 emissions in the United States were summarized by major fuel (i.e., coal, petroleum, natural gas, geothermal) and consuming sector (i.e., residential, commercial, industrial, transportation, electricity generation, and U.S. territories). Emission estimates are expressed in teragrams of carbon dioxide equivalents (Tg CO_2 Eq.). To convert from C content to CO_2 emissions, the fraction of C that is oxidized was applied. This fraction was 100 percent based on guidance in IPCC (2006).

To determine total emissions by final end-use sector, emissions from electricity generation were distributed to each end-use sector according to its share of aggregate electricity consumption (see Table A-30). This pro-rated approach to allocating emissions from electricity generation may overestimate or underestimate emissions for particular sectors due to differences in the average C content of fuel mixes burned to generate electricity.

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[3] See Waste Combustion section of the Energy chapter and Annex 3.6 for a discussion of emissions from the combustion of plastics in the municipal solid waste stream.

[4] Refer to the International Bunker Fuels section of the Energy chapter for a description of the methodology for distinguishing between bunker and non-bunker fuel consumption.

Table A-10: 2005 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**10.4**	**83.9**	**1,300.3**	**NE**	**20,737.2**	**43.1**	**22,174.8**	**1.0**	**8.0**	**122.2**	**NE**	**1,958.4**	**4.0**	**2,093.6**
Residential Coal	10.4						10.4	1.0						1.0
Commercial Coal		83.9					83.9		8.0					8.0
Industrial Other Coal			1,300.3				1,300.3			122.2				122.2
Transportation Coal				NE										NE
Electric Power Coal					20,737.2		20,737.2					1,958.4		1,958.4
U.S. Territory Coal (bit)						43.1	43.1						4.0	4.0
Natural Gas	**4,952.8**	**3,146.8**	**7,294.6**	**600.0**	**6,033.5**	**24.73**	**22,052.4**	**262.8**	**167.0**	**387.0**	**31.8**	**320.1**	**1.3**	**1,170.0**
Total Petroleum	**1,368.8**	**699.2**	**4,514.4**	**26,007.8**	**1,234.5**	**641.4**	**34,466.2**	**95.0**	**50.9**	**330.9**	**1,861.0**	**102.3**	**47.2**	**2,487.2**
Asphalt & Road Oil														
Aviation Gasoline				35.4			35.4				2.4			2.4
Distillate Fuel Oil	772.9	404.9	1,131.6	6,221.0	114.6	123.2	8,768.2	56.5	29.6	82.8	455.1	8.4	9.0	641.4
Jet Fuel				2,591.6	NA	77.0	2,668.6				183.7		5.5	189.2
Kerosene	91.7	22.2	30.5			10.9	155.4	6.6	1.6	2.2			0.8	11.2
LPG	504.2	89.0	583.5	17.1		10.8	1,204.5	31.8	5.6	36.8	1.1		0.7	75.9
Lubricants														
Motor Gasoline		48.7	373.7	16,682.0		221.5	17,326.0		3.5	26.5	1,182.4		15.7	1,228.0
Residual Fuel		134.1	248.5	460.7	876.5	198.1	1,917.8		10.6	19.6	36.3	69.1	15.6	151.1
Other Petroleum														
AvGas Blend Components			8.3				8.3			0.6				0.6
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			45.9				45.9			3.1				3.1
Petroleum Coke		0.3	660.1		243.5		903.9		0.0	67.4		24.9		92.3
Still Gas			1,429.4				1,429.4			91.8				91.8
Special Naphtha														
Unfinished Oils			2.8				2.8			0.2				0.2
Waxes														
Geothermal					**49.0**		**49.0**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,332.0**	**3,929.8**	**13,109.3**	**26,607.9**	**28,054.2**	**709.3**	**78,742.4**	**358.7**	**225.8**	**840.1**	**1,892.8**	**2,381.2**	**52.5**	**5,751.2**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-11: 2004 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**13.7**	**100.6**	**1,343.0**	**NE**	**20,305.0**	**42.6**	**21,804.9**	**1.3**	**9.6**	**126.2**	**NE**	**1,917.6**	**3.9**	**2,058.6**
Residential Coal	13.7						13.7	1.3						1.3
Commercial Coal		100.6					100.6		9.6					9.6
Industrial Other Coal			1,343.0				1,343.0			126.2				126.2
Transportation Coal				NE										NE
Electric Power Coal					20,305.0		20,305.0					1,917.6		1,917.6
U.S. Territory Coal (bit)						42.6	42.6						3.9	3.9
Natural Gas	**5,016.4**	**3,226.5**	**7,949.8**	**608.4**	**5,611.3**	**24.66**	**22,437.0**	**266.2**	**171.2**	**421.8**	**32.3**	**297.7**	**1.3**	**1,190.4**
Total Petroleum	**1,474.9**	**723.0**	**4,476.8**	**25,616.9**	**1,212.4**	**661.8**	**34,165.7**	**102.5**	**52.5**	**327.6**	**1,832.2**	**100.1**	**48.7**	**2,463.6**
Asphalt & Road Oil														
Aviation Gasoline				31.2			31.2				2.2			2.2
Distillate Fuel Oil	859.3	437.5	1,117.9	6,017.8	111.3	126.9	8,670.7	62.9	32.0	81.8	440.2	8.1	9.3	634.3
Jet Fuel				2,504.4	NA	78.7	2,583.2				177.5		5.6	183.1
Kerosene	84.8	20.5	28.2			11.3	144.8	6.1	1.5	2.0			0.8	10.5
LPG	530.9	93.7	604.8	18.0		11.1	1,258.5	33.5	5.9	38.1	1.1		0.7	79.4
Lubricants														
Motor Gasoline		48.6	372.3	16,659.6		228.9	17,309.3		3.4	26.4	1,180.8		16.2	1,226.8
Residual Fuel		122.5	204.7	385.8	879.0	204.8	1,796.9		9.7	16.1	30.4	69.3	16.1	141.6
Other Petroleum														
AvGas Blend Components			10.6				10.6			0.7				0.7
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			52.1				52.1			3.5				3.5
Petroleum Coke		0.3	679.2		222.1		901.5		0.0	69.4		22.7		92.1
Still Gas			1,482.6				1,482.6			95.2				95.2
Special Naphtha														
Unfinished Oils			(75.6)				(75.6)			(5.6)				(5.6)
Waxes														
Geothermal					**49.0**		**49.0**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,505.0**	**4,050.1**	**13,769.6**	**26,225.2**	**27,177.7**	**729.0**	**78,456.5**	**369.9**	**233.3**	**875.6**	**1,864.5**	**2,315.8**	**54.0**	**5,713.0**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-12: 2003 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**12.2**	**82.0**	**1,319.0**	**NE**	**20,184.7**	**44.4**	**21,642.4**	**1.2**	**7.8**	**124.0**	**NE**	**1,906.2**	**4.1**	**2,043.3**
Residential Coal	12.2						12.2	1.2						1.2
Commercial Coal		82.0					82.0		7.8					7.8
Industrial Other Coal			1,319.0				1,319.0			124.0				124.0
Transportation Coal				NE										NE
Electric Power Coal					20,184.7		20,184.7					1,906.2		1,906.2
U.S. Territory Coal (bit)						44.4	44.4						4.1	4.1
Natural Gas	**5,247.0**	**3,284.4**	**7,937.9**	**629.9**	**5,263.6**	**26.94**	**22,389.7**	**278.4**	**174.3**	**421.2**	**33.4**	**279.3**	**1.4**	**1,187.9**
Total Petroleum	**1,503.2**	**751.9**	**4,274.7**	**24,855.9**	**1,205.0**	**621.8**	**33,212.5**	**104.2**	**54.5**	**313.2**	**1,777.1**	**98.1**	**45.8**	**2,392.9**
Asphalt & Road Oil														
Aviation Gasoline				30.2			30.2				2.1			2.1
Distillate Fuel Oil	868.9	462.4	1,079.7	5,683.0	161.0	120.5	8,375.6	63.6	33.8	79.0	415.7	11.8	8.8	612.7
Jet Fuel				2,435.8	NA	76.1	2,511.9				172.7		5.4	178.0
Kerosene	70.3	18.6	24.1			10.7	123.7	5.1	1.3	1.7			0.8	8.9
LPG	564.0	99.5	523.1	15.7		10.5	1,212.8	35.6	6.3	33.0	1.0		0.7	76.5
Lubricants														
Motor Gasoline		59.9	324.1	16,359.3		210.1	16,953.3		4.2	23.0	1,159.5		14.9	1,201.6
Residual Fuel		111.1	176.4	331.9	869.4	193.9	1,682.8		8.8	13.9	26.2	68.5	15.3	132.6
Other Petroleum														
AvGas Blend Components			7.5				7.5			0.5				0.5
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			51.7				51.7			3.5				3.5
Petroleum Coke		0.3	661.2		174.7		836.2		0.0	67.5		17.8		85.4
Still Gas			1,477.3				1,477.3			94.8				94.8
Special Naphtha														
Unfinished Oils			(50.4)				(50.4)			(3.7)				(3.7)
Waxes														
Geothermal					**49.2**		**49.2**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,762.4**	**4,118.3**	**13,531.6**	**25,485.8**	**26,702.5**	**693.2**	**77,293.8**	**383.8**	**236.6**	**858.3**	**1,810.5**	**2,284.0**	**51.3**	**5,624.5**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-13: 2002 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**12.2**	**89.8**	**1,312.8**	**NE**	**19,782.8**	**21.1**	**21,218.7**	**1.2**	**8.6**	**123.4**	**NE**	**1,868.3**	**1.9**	**2,003.3**
Residential Coal	12.2						12.2	1.2						1.2
Commercial Coal		89.8					89.8		8.6					8.6
Industrial Other Coal			1,312.8				1,312.8			123.4				123.4
Transportation Coal				NE										NE
Electric Power Coal					19,782.8		19,782.8					1,868.3		1,868.3
U.S. Territory Coal (bit)						21.1	21.1						1.9	1.9
Natural Gas	**5,030.6**	**3,235.4**	**8,210.9**	**701.6**	**5,785.3**	**22.85**	**22,986.6**	**266.9**	**171.7**	**435.6**	**37.2**	**307.0**	**1.2**	**1,219.6**
Total Petroleum	**1,365.5**	**630.9**	**4,082.8**	**24,807.1**	**961.3**	**556.8**	**32,404.4**	**94.4**	**45.5**	**298.7**	**1,775.1**	**79.1**	**41.1**	**2,333.9**
Asphalt & Road Oil														
Aviation Gasoline				33.7			33.7				2.3			2.3
Distillate Fuel Oil	762.8	394.0	1,056.8	5,605.1	127.4	92.8	8,038.9	55.8	28.8	77.3	410.0	9.3	6.8	588.0
Jet Fuel				2,478.0	NA	61.8	2,539.8				175.6		4.4	180.0
Kerosene	59.9	16.0	13.8			8.2	97.9	4.3	1.2	1.0			0.6	7.1
LPG	542.8	95.8	579.5	13.5		11.2	1,242.7	34.2	6.0	36.6	0.8		0.7	78.4
Lubricants														
Motor Gasoline		45.1	309.0	16,290.0		189.4	16,833.4		3.2	21.9	1,155.8		13.4	1,194.3
Residual Fuel		79.8	146.1	386.9	658.7	193.6	1,465.1		6.3	11.5	30.5	51.9	15.3	115.4
Other Petroleum														
AvGas Blend Components			7.5				7.5			0.5				0.5
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			52.4				52.4			3.5				3.5
Petroleum Coke		0.2	650.0		175.2		825.4		0.0	66.4		17.9		84.3
Still Gas			1,403.3				1,403.3			90.1				90.1
Special Naphtha														
Unfinished Oils			(135.7)				(135.7)			(10.1)				(10.1)
Waxes														
Geothermal					**49.4**		**49.4**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,408.4**	**3,956.0**	**13,606.4**	**25,508.8**	**26,578.9**	**600.7**	**76,659.2**	**362.4**	**225.7**	**857.7**	**1,812.3**	**2,254.7**	**44.3**	**5,557.2**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-14: 2001 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**12.0**	**96.9**	**1,420.6**	**NE**	**19,613.7**	**10.8**	**21,153.8**	**1.1**	**9.2**	**133.5**	**NE**	**1,852.3**	**1.0**	**1,997.2**
Residential Coal	12.0						12.0	1.1						1.1
Commercial Coal		96.9					96.9		9.2					9.2
Industrial Other Coal			1,420.6				1,420.6			133.5				133.5
Transportation Coal				NE										NE
Electric Power Coal					19,613.7		19,613.7					1,852.3		1,852.3
U.S. Territory Coal (bit)						10.8	10.8						1.0	1.0
Natural Gas	**4,909.7**	**3,110.4**	**8,033.4**	**658.0**	**5,481.2**	**22.92**	**22,215.6**	**260.5**	**165.0**	**426.2**	**34.9**	**290.8**	**1.2**	**1,178.7**
Total Petroleum	**1,472.4**	**704.6**	**4,232.0**	**24,116.4**	**1,276.6**	**632.2**	**32,434.2**	**102.2**	**50.9**	**310.2**	**1,723.3**	**102.0**	**46.8**	**2,335.5**
Asphalt & Road Oil														
Aviation Gasoline				34.9			34.9				2.4			2.4
Distillate Fuel Oil	842.1	471.3	1,193.4	5,417.4	170.5	109.4	8,204.1	61.6	34.5	87.3	396.3	12.5	8.0	600.1
Jet Fuel				2,597.9	NA	98.9	2,696.7				184.1		7.0	191.1
Kerosene	95.1	31.4	23.2			0.9	150.6	6.9	2.3	1.7			0.1	10.9
LPG	535.2	94.5	500.6	12.9		7.0	1,150.2	33.8	6.0	31.6	0.8		0.4	72.6
Lubricants														
Motor Gasoline		37.4	295.0	15,893.8		187.6	16,413.9		2.7	20.9	1,127.1		13.3	1,164.0
Residual Fuel		69.9	146.7	159.5	1,002.8	228.4	1,607.2		5.5	11.6	12.6	79.0	18.0	126.6
Other Petroleum														
AvGas Blend Components			6.1				6.1			0.4				0.4
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			61.6				61.6			4.1				4.1
Petroleum Coke		0.2	650.0		103.2		753.4		0.0	66.4		10.5		76.9
Still Gas			1,430.7				1,430.7			91.9				91.9
Special Naphtha														
Unfinished Oils			(75.4)				(75.4)			(5.6)				(5.6)
Waxes														
Geothermal					**46.9**		**46.9**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,394.1**	**3,911.9**	**13,685.9**	**24,774.4**	**26,418.3**	**665.9**	**75,850.5**	**363.9**	**225.1**	**869.9**	**1,758.2**	**2,245.5**	**49.0**	**5,511.7**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-15: 2000 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**11.4**	**91.9**	**1,420.6**	**NE**	**20,220.2**	**10.3**	**21,754.3**	**1.1**	**8.8**	**133.5**	**NE**	**1,909.6**	**0.9**	**2,053.9**
Residential Coal	11.4						11.4	1.1						1.1
Commercial Coal		91.9					91.9		8.8					8.8
Industrial Other Coal			1,420.6				1,420.6			133.5				133.5
Transportation Coal				NE										NE
Electric Power Coal					20,220.2		20,220.2					1,909.6		1,909.6
U.S. Territory Coal (bit)						10.3	10.3						0.9	0.9
Natural Gas	**5,126.1**	**3,265.2**	**8,746.0**	**672.0**	**5,315.7**	**12.67**	**23,137.6**	**272.0**	**173.2**	**464.0**	**35.7**	**282.0**	**0.7**	**1,227.6**
Total Petroleum	**1,452.6**	**696.4**	**3,797.5**	**24,443.8**	**1,144.3**	**471.7**	**32,006.3**	**100.5**	**50.3**	**277.4**	**1,748.7**	**91.5**	**34.6**	**2,303.0**
Asphalt & Road Oil														
Aviation Gasoline				36.3			36.3				2.5			2.5
Distillate Fuel Oil	794.3	431.0	1,042.1	5,395.7	174.8	71.3	7,909.3	58.1	31.5	76.2	394.7	12.8	5.2	578.6
Jet Fuel				2,735.9	NA	74.1	2,810.0				193.9		5.2	199.2
Kerosene	94.6	29.7	15.6			2.4	142.2	6.8	2.1	1.1			0.2	10.3
LPG	563.7	99.5	605.3	11.2		8.0	1,287.7	35.6	6.3	38.2	0.7		0.5	81.2
Lubricants														
Motor Gasoline		44.5	150.2	15,821.3		185.1	16,201.1		3.2	10.7	1,121.9		13.1	1,148.9
Residual Fuel		91.6	184.1	443.5	870.8	130.9	1,720.8		7.2	14.5	34.9	68.6	10.3	135.6
Other Petroleum														
AvGas Blend Components			3.8				3.8			0.3				0.3
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			106.5				106.5			7.1				7.1
Petroleum Coke		0.2	655.4		98.6		754.2		0.0	66.9		10.1		77.0
Still Gas			1,435.6				1,435.6			92.2				92.2
Special Naphtha														
Unfinished Oils			(401.2)				(401.2)			(29.8)				(29.8)
Waxes														
Geothermal					**48.1**		**48.1**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,590.0**	**4,053.5**	**13,964.0**	**25,115.8**	**26,728.2**	**494.6**	**76,946.2**	**373.5**	**232.3**	**875.0**	**1,784.4**	**2,283.5**	**36.2**	**5,584.9**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-16: 1999 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	Res.	Comm.	Ind.	Trans.	Elec.	Terr.	Total	Res.	Comm.	Ind.	Trans.	Elec.	Terr.	Total
Total Coal	**14.0**	**102.5**	**1,362.2**	**NE**	**19,279.5**	**10.2**	**20,768.4**	**1.3**	**9.8**	**128.0**	**NE**	**1,820.7**	**0.9**	**1,960.8**
Residential Coal	14.0						14.0	1.3						1.3
Commercial Coal		102.5					102.5		9.8					9.8
Industrial Other Coal			1,362.2				1,362.2			128.0				128.0
Transportation Coal				NE										NE
Electric Power Coal					19,279.5		19,279.5					1,820.7		1,820.7
U.S. Territory Coal (bit)						10.2	10.2						0.9	0.9
Natural Gas	**4,858.0**	**3,129.9**	**8,597.9**	**675.3**	**4,925.6**	**-**	**22,186.7**	**257.7**	**166.1**	**456.2**	**35.8**	**261.3**		**1,177.2**
Total Petroleum	**1,377.4**	**611.0**	**3,684.2**	**23,772.7**	**1,211.4**	**461.0**	**31,117.6**	**95.4**	**44.1**	**270.9**	**1,697.9**	**97.3**	**34.0**	**2,239.6**
Asphalt & Road Oil														
Aviation Gasoline				39.2			39.2				2.7			2.7
Distillate Fuel Oil	732.5	388.0	1,038.9	5,169.8	140.1	79.4	7,548.7	53.6	28.4	76.0	378.2	10.3	5.8	552.2
Jet Fuel				2,641.2	NA	59.5	2,700.7				187.2		4.2	191.4
Kerosene	111.2	26.9	12.8			3.7	154.7	8.0	1.9	0.9			0.3	11.2
LPG	533.8	94.2	435.0	13.5		8.3	1,084.7	33.8	6.0	27.5	0.9		0.5	68.6
Lubricants														
Motor Gasoline		28.4	151.7	15,733.4		164.0	16,077.6		2.0	10.8	1,115.1		11.6	1,139.5
Residual Fuel		73.3	150.9	175.7	958.7	146.0	1,504.6		5.8	11.9	13.8	75.5	11.5	118.6
Other Petroleum														
AvGas Blend Components			6.4				6.4			0.4				0.4
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			103.5				103.5			6.9				6.9
Petroleum Coke		0.1	651.9		112.5		764.5		0.0	66.6		11.5		78.1
Still Gas			1,421.1				1,421.1			91.2				91.2
Special Naphtha														
Unfinished Oils			(287.9)				(287.9)			(21.3)				(21.3)
Waxes														
Geothermal					**50.6**		**50.6**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,249.4**	**3,843.4**	**13,644.3**	**24,448.1**	**25,467.0**	**471.2**	**74,123.3**	**354.5**	**219.9**	**855.1**	**1,733.7**	**2,179.7**	**34.9**	**5,377.9**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-17: 1998 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**11.5**	**93.4**	**1,409.4**	**NE**	**19,215.7**	**10.5**	**20,740.6**	**1.1**	**8.9**	**132.5**	**NE**	**1,814.7**	**1.0**	**1,958.2**
Residential Coal	11.5						11.5	1.1						1.1
Commercial Coal		93.4					93.4		8.9					8.9
Industrial Other Coal			1,409.4				1,409.4			132.5				132.5
Transportation Coal				NE										NE
Electric Power Coal					19,215.7		19,215.7					1,814.7		1,814.7
U.S. Territory Coal (bit)						10.5	10.5						1.0	1.0
Natural Gas	**4,669.4**	**3,098.5**	**8,980.9**	**666.1**	**4,698.4**	**-**	**22,113.3**	**247.7**	**164.4**	**476.5**	**35.3**	**249.3**		**1,173.3**
Total Petroleum	**1,242.9**	**621.4**	**3,648.8**	**22,917.1**	**1,306.2**	**445.4**	**30,182.0**	**86.5**	**45.1**	**269.3**	**1,635.8**	**105.0**	**32.8**	**2,174.5**
Asphalt & Road Oil														
Aviation Gasoline				35.5			35.5				2.5			2.5
Distillate Fuel Oil	701.0	389.5	1,088.5	4,874.3	135.7	71.9	7,260.9	51.3	28.5	79.6	356.6	9.9	5.3	531.1
Jet Fuel				2,566.1	NA	59.9	2,625.9				181.9		4.2	186.1
Kerosene	108.3	31.2	22.1			6.3	167.8	7.8	2.3	1.6			0.5	12.1
LPG	433.6	76.5	303.9	16.6		5.9	836.5	27.4	4.8	19.2	1.0		0.4	52.8
Lubricants														
Motor Gasoline		39.0	199.5	15,345.7		160.3	15,744.5		2.8	14.1	1,087.7		11.4	1,115.9
Residual Fuel		85.2	173.3	78.9	1,047.0	141.1	1,525.5		6.7	13.7	6.2	82.5	11.1	120.2
Other Petroleum														
AvGas Blend Components			4.0				4.0			0.3				0.3
Crude Oil														
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			89.7				89.7			6.0				6.0
Petroleum Coke		0.1	644.6		123.6		768.3		0.0	65.8		12.6		78.5
Still Gas			1,437.3				1,437.3			92.3				92.3
Special Naphtha														
Unfinished Oils			(313.9)				(313.9)			(23.3)				(23.3)
Waxes														
Geothermal					**50.4**		**50.4**					**0.4**		**0.4**
TOTAL (All Fuels)	**5,923.9**	**3,813.3**	**14,039.0**	**23,583.2**	**25,270.7**	**456.0**	**73,086.2**	**335.3**	**218.4**	**878.2**	**1,671.2**	**2,169.4**	**33.8**	**5,306.3**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-18: 1997 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**16.0**	**129.4**	**1,462.5**	**NE**	**18,904.5**	**10.4**	**20,522.9**	**1.5**	**12.3**	**137.5**	**NE**	**1,785.3**	**1.0**	**1,937.6**
Residential Coal	16.0						16.0	1.5						1.5
Commercial Coal		129.4					129.4		12.3					12.3
Industrial Other Coal			1,462.5				1,462.5			137.5				137.5
Transportation Coal				NE										NE
Electric Power Coal					18,904.5		18,904.5					1,785.3		1,785.3
U.S. Territory Coal (bit)						10.4	10.4						1.0	1.0
Natural Gas	**5,118.3**	**3,301.7**	**9,203.7**	**780.3**	**4,146.1**	**-**	**22,550.2**	**271.6**	**175.2**	**488.3**	**41.4**	**220.0**		**1,196.4**
Total Petroleum	**1,343.4**	**660.9**	**4,001.7**	**22,402.0**	**926.8**	**445.3**	**29,780.1**	**93.5**	**48.0**	**293.3**	**1,600.7**	**74.8**	**32.8**	**2,143.0**
Asphalt & Road Oil														
Aviation Gasoline				39.7			39.7				2.7			2.7
Distillate Fuel Oil	789.8	400.9	1,076.1	4,790.8	110.6	81.6	7,249.8	57.8	29.3	78.7	350.4	8.1	6.0	530.3
Jet Fuel				2,528.1	NA	62.1	2,590.2				179.2		4.4	183.6
Kerosene	92.9	24.7	18.8			4.0	140.3	6.7	1.8	1.4			0.3	10.1
LPG	460.8	81.3	463.7	13.4		6.5	1,025.7	29.0	5.1	29.2	0.8		0.4	64.6
Lubricants														
Motor Gasoline		42.7	211.9	14,893.4		160.0	15,308.0		3.0	15.0	1,056.7		11.4	1,086.1
Residual Fuel		111.2	235.6	136.5	714.6	131.1	1,329.0		8.8	18.6	10.8	56.3	10.3	104.7
Other Petroleum														
AvGas Blend Components			9.1				9.1			0.6				0.6
Crude Oil			4.6				4.6			0.3				0.3
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			30.0				30.0			2.0				2.0
Petroleum Coke		0.1	609.7		101.6		711.4		0.0	62.3		10.4		72.6
Still Gas			1,445.1				1,445.1			92.8				92.8
Special Naphtha														
Unfinished Oils			(102.9)				(102.9)			(7.6)				(7.6)
Waxes														
Geothermal					**50.2**		**50.2**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,477.7**	**4,092.0**	**14,668.0**	**23,182.3**	**24,027.7**	**455.7**	**72,903.4**	**366.6**	**235.6**	**919.0**	**1,642.1**	**2,080.5**	**33.7**	**5,277.5**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-19: 1996 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**16.6**	**121.6**	**1,498.9**	**NE**	**18,429.0**	**10.3**	**20,076.4**	**1.6**	**11.6**	**140.7**	**NE**	**1,739.6**	**1.0**	**1,894.4**
Residential Coal	16.6						16.6	1.6						1.6
Commercial Coal		121.6					121.6		11.6					11.6
Industrial Other Coal			1,498.9				1,498.9			140.7				140.7
Transportation Coal				NE										NE
Electric Power Coal					18,429.0		18,429.0					1,739.6		1,739.6
U.S. Territory Coal (bit)						10.3	10.3						1.0	1.0
Natural Gas	**5,382.9**	**3,243.5**	**9,198.1**	**736.9**	**3,883.0**	**-**	**22,444.5**	**285.6**	**172.1**	**488.0**	**39.1**	**206.0**		**1,190.8**
Total Petroleum	**1,436.3**	**724.3**	**4,040.2**	**22,166.4**	**817.4**	**434.6**	**29,619.1**	**100.2**	**52.8**	**296.7**	**1,585.3**	**65.6**	**31.9**	**2,132.5**
Asphalt & Road Oil														
Aviation Gasoline				37.4			37.4				2.6			2.6
Distillate Fuel Oil	874.2	455.9	1,111.3	4,500.4	109.4	76.5	7,127.6	63.9	33.4	81.3	329.2	8.0	5.6	521.4
Jet Fuel				2,545.9	NA	78.5	2,624.4				180.5		5.6	186.0
Kerosene	88.8	21.0	18.3			3.0	131.1	6.4	1.5	1.3			0.2	9.5
LPG	473.3	83.5	436.9	14.7		7.3	1,015.7	29.8	5.3	27.5	0.9		0.5	64.1
Lubricants														
Motor Gasoline		26.5	199.9	14,753.1		151.4	15,130.9		1.9	14.2	1,047.3		10.7	1,074.1
Residual Fuel		137.2	281.7	314.9	628.4	118.0	1,480.1		10.8	22.2	24.8	49.5	9.3	116.6
Other Petroleum														
AvGas Blend Components			7.0				7.0			0.5				0.5
Crude Oil			13.7				13.7			1.0				1.0
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			38.5				38.5			2.6				2.6
Petroleum Coke		0.1	608.7		79.6		688.4		0.0	62.2		8.1		70.3
Still Gas			1,437.1				1,437.1			92.3				92.3
Special Naphtha														
Unfinished Oils			(112.8)				(112.8)			(8.4)				(8.4)
Waxes														
Geothermal					**48.9**		**48.9**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,835.8**	**4,089.4**	**14,737.1**	**22,903.3**	**23,178.3**	**445.0**	**72,188.9**	**387.4**	**236.5**	**925.4**	**1,624.4**	**2,011.6**	**32.8**	**5,218.1**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-20: 1995 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**17.5**	**116.8**	**1,521.7**	**NE**	**17,466.3**	**10.2**	**19,132.4**	**1.7**	**11.1**	**143.0**	**NE**	**1,648.7**	**0.9**	**1,805.5**
Residential Coal	17.5						17.5	1.7						1.7
Commercial Coal		116.8					116.8		11.1					11.1
Industrial Other Coal			1,521.7				1,521.7			143.0				143.0
Transportation Coal				NE										NE
Electric Power Coal					17,466.3		17,466.3					1,648.7		1,648.7
U.S. Territory Coal (bit)						10.2	10.2						0.9	0.9
Natural Gas	**4,981.3**	**3,112.9**	**8,900.8**	**724.0**	**4,325.5**	**-**	**22,044.5**	**264.3**	**165.2**	**472.2**	**38.4**	**229.5**		**1,169.6**
Total Petroleum	**1,293.5**	**684.5**	**3,642.9**	**21,677.0**	**754.6**	**461.8**	**28,514.2**	**90.5**	**50.1**	**267.5**	**1,551.8**	**60.7**	**34.0**	**2,054.6**
Asphalt & Road Oil														
Aviation Gasoline				39.6			39.6				2.7			2.7
Distillate Fuel Oil	814.9	431.3	1,010.7	4,318.9	108.1	89.5	6,773.4	59.6	31.6	73.9	315.9	7.9	6.5	495.5
Jet Fuel				2,424.1	NA	75.7	2,499.9				171.9		5.4	177.2
Kerosene	74.3	22.1	15.4			3.6	115.4	5.4	1.6	1.1			0.3	8.3
LPG	404.2	71.3	432.5	16.8		5.6	930.5	25.5	4.5	27.3	1.1		0.4	58.7
Lubricants														
Motor Gasoline		18.1	200.1	14,490.3		146.7	14,855.2		1.3	14.2	1,029.7		10.4	1,055.6
Residual Fuel		141.5	284.7	387.3	566.0	140.7	1,520.1		11.1	22.4	30.5	44.6	11.1	119.8
Other Petroleum														
AvGas Blend Components			5.3				5.3			0.4				0.4
Crude Oil			14.5				14.5			1.1				1.1
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			34.5				34.5			2.3				2.3
Petroleum Coke		0.1	588.7		80.6		669.4		0.0	60.1		8.2		68.4
Still Gas			1,377.3				1,377.3			88.4				88.4
Special Naphtha														
Unfinished Oils			(320.9)				(320.9)			(23.8)				(23.8)
Waxes														
Geothermal					**45.6**		**45.6**					**0.3**		**0.3**
TOTAL (All Fuels)	**6,292.2**	**3,914.2**	**14,065.4**	**22,400.9**	**22,592.0**	**472.0**	**69,736.7**	**356.4**	**226.4**	**882.7**	**1,590.2**	**1,939.3**	**35.0**	**5,030.0**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-21: 1994 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**20.8**	**118.1**	**1,575.0**	**NE**	**17,260.9**	**10.0**	**18,984.9**	**2.0**	**11.2**	**148.0**	**NE**	**1,627.8**	**0.9**	**1,789.9**
Residential Coal	20.8						20.8	2.0						2.0
Commercial Coal		118.1					118.1		11.2					11.2
Industrial Other Coal			1,575.0				1,575.0			148.0				148.0
Transportation Coal				NE										NE
Electric Power Coal					17,260.9		17,260.9					1,627.8		1,627.8
U.S. Territory Coal (bit)						10.0	10.0						0.9	0.9
Natural Gas	**4,988.3**	**2,979.0**	**8,423.8**	**708.5**	**4,000.1**	**-**	**21,099.7**	**264.7**	**158.1**	**446.9**	**37.6**	**212.2**		**1,119.5**
Total Petroleum	**1,325.5**	**738.1**	**3,853.2**	**21,261.6**	**1,058.8**	**506.3**	**28,743.5**	**92.9**	**54.2**	**282.6**	**1,525.3**	**84.4**	**37.5**	**2,076.9**
Asphalt & Road Oil														
Aviation Gasoline				38.1			38.1				2.6			2.6
Distillate Fuel Oil	865.1	451.5	994.1	4,164.4	120.1	118.8	6,714.1	63.3	33.0	72.7	304.6	8.8	8.7	491.1
Jet Fuel				2,484.7	NA	65.8	2,550.5				176.3		4.7	180.9
Kerosene	64.9	19.5	16.9			3.0	104.3	4.7	1.4	1.2			0.2	7.5
LPG	395.4	69.8	450.8	32.2		7.3	955.5	25.0	4.4	28.5	2.0		0.5	60.3
Lubricants														
Motor Gasoline		25.2	192.4	14,184.0		147.4	14,549.0		1.8	13.7	1,011.6		10.5	1,037.6
Residual Fuel		172.0	368.4	358.1	869.0	164.1	1,931.5		13.5	29.0	28.2	68.5	12.9	152.2
Other Petroleum														
AvGas Blend Components			6.1				6.1			0.4				0.4
Crude Oil			18.7				18.7			1.4				1.4
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			80.8				80.8			5.4				5.4
Petroleum Coke		0.1	586.8		69.7		656.6		0.0	59.9		7.1		67.1
Still Gas			1,417.5				1,417.5			91.0				91.0
Special Naphtha														
Unfinished Oils			(279.2)				(279.2)			(20.7)				(20.7)
Waxes														
Geothermal					**53.0**		**53.0**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,334.6**	**3,835.2**	**13,852.1**	**21,970.1**	**22,372.8**	**516.3**	**68,881.0**	**359.6**	**223.5**	**877.6**	**1,562.9**	**1,924.8**	**38.4**	**4,986.7**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-22: 1993 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**25.7**	**117.3**	**1,574.6**	**NE**	**17,195.9**	**9.6**	**18,923.2**	**2.5**	**11.2**	**147.8**	**NE**	**1,620.9**	**0.9**	**1,783.2**
Residential Coal	25.7						25.7	2.5						2.5
Commercial Coal		117.3					117.3		11.2					11.2
Industrial Other Coal			1,574.6				1,574.6			147.8				147.8
Transportation Coal				NE										NE
Electric Power Coal					17,195.9		17,195.9					1,620.9		1,620.9
U.S. Territory Coal (bit)						9.6	9.6						0.9	0.9
Natural Gas	**5,095.2**	**2,941.7**	**8,445.7**	**644.7**	**3,559.8**	**-**	**20,687.2**	**270.3**	**156.1**	**448.1**	**34.2**	**188.9**		**1,097.6**
Total Petroleum	**1,358.4**	**734.5**	**3,719.8**	**20,707.3**	**1,123.8**	**459.9**	**28,103.6**	**95.3**	**53.9**	**273.7**	**1,484.7**	**89.9**	**34.1**	**2,031.6**
Asphalt & Road Oil														
Aviation Gasoline				38.4			38.4				2.7			2.7
Distillate Fuel Oil	884.2	447.7	1,007.2	3,886.9	86.5	104.9	6,417.3	64.7	32.7	73.7	284.3	6.3	7.7	469.4
Jet Fuel				2,366.9	NA	62.1	2,429.0				168.1		4.4	172.6
Kerosene	75.6	14.0	13.1			3.8	106.5	5.5	1.0	0.9			0.3	7.7
LPG	398.6	70.3	443.3	19.0		4.9	936.2	25.2	4.4	28.0	1.2		0.3	59.1
Lubricants														
Motor Gasoline		29.6	179.5	14,028.6		128.3	14,365.9		2.1	12.8	999.4		9.1	1,023.5
Residual Fuel		172.7	391.5	367.5	958.7	155.9	2,046.3		13.6	30.8	29.0	75.5	12.3	161.2
Other Petroleum														
AvGas Blend Components			0.1				0.1			0.0				0.0
Crude Oil			21.2				21.2			1.6				1.6
MoGas Blend Components														
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			56.4				56.4			3.8				3.8
Petroleum Coke		0.2	601.8		78.7		680.6		0.0	61.5		8.0		69.5
Still Gas			1,401.8				1,401.8			90.0				90.0
Special Naphtha														
Unfinished Oils			(396.0)				(396.0)			(29.4)				(29.4)
Waxes														
Geothermal					**57.3**		**57.3**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,479.4**	**3,793.5**	**13,740.1**	**21,352.0**	**21,936.8**	**469.5**	**67,771.3**	**368.1**	**221.2**	**869.6**	**1,518.9**	**1,900.1**	**35.0**	**4,912.9**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-23: 1992 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**25.6**	**116.6**	**1,536.3**	**NE**	**16,465.6**	**8.8**	**18,152.9**	**2.5**	**11.2**	**144.3**	**NE**	**1,551.3**	**0.8**	**1,710.0**
Residential Coal	25.6						25.6	2.5						2.5
Commercial Coal		116.6					116.6		11.2					11.2
Industrial Other Coal			1,536.3				1,536.3			144.3				144.3
Transportation Coal				NE										NE
Electric Power Coal					16,465.6		16,465.6					1,551.3		1,551.3
U.S. Territory Coal (bit)						8.8	8.8						0.8	0.8
Natural Gas	**4,835.5**	**2,889.6**	**8,320.2**	**608.1**	**3,534.1**	**-**	**20,187.4**	**256.6**	**153.3**	**441.4**	**32.3**	**187.5**		**1,071.1**
Total Petroleum	**1,381.9**	**830.6**	**4,062.2**	**20,081.7**	**990.7**	**444.9**	**27,792.0**	**97.2**	**61.0**	**295.4**	**1,439.6**	**78.7**	**32.9**	**2,004.8**
Asphalt & Road Oil														
Aviation Gasoline				41.1			41.1				2.8			2.8
Distillate Fuel Oil	934.4	483.3	1,049.0	3,657.7	73.5	91.8	6,289.7	68.4	35.4	76.7	267.6	5.4	6.7	460.1
Jet Fuel				2,348.7	NA	61.3	2,410.0				167.0		4.4	171.3
Kerosene	65.0	11.1	9.8			3.3	89.2	4.7	0.8	0.7			0.2	6.4
LPG	382.5	67.5	469.1	18.3		11.9	949.3	24.1	4.3	29.6	1.2		0.7	59.9
Lubricants														
Motor Gasoline		79.6	194.2	13,615.7		122.1	14,011.7		5.7	13.8	969.5		8.7	997.7
Residual Fuel		189.1	328.4	400.1	872.2	154.6	1,944.3		14.9	25.9	31.5	68.7	12.2	153.2
Other Petroleum														
AvGas Blend Components			0.2				0.2			0.0				0.0
Crude Oil			27.4				27.4			2.0				2.0
MoGas Blend Components			75.7				75.7			5.4				5.4
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			261.0				261.0			17.5				17.5
Petroleum Coke		0.1	566.6		45.0		611.7		0.0	57.9		4.6		62.5
Still Gas			1,435.7				1,435.7			92.2				92.2
Special Naphtha														
Unfinished Oils			(354.8)				(354.8)			(26.3)				(26.3)
Waxes														
Geothermal					**55.1**		**55.1**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,243.0**	**3,836.8**	**13,918.7**	**20,689.8**	**21,045.4**	**453.7**	**66,187.4**	**356.2**	**225.5**	**881.1**	**1,471.9**	**1,817.9**	**33.7**	**4,786.3**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-24: 1991 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**25.4**	**115.5**	**1,577.3**	**NE**	**16,249.7**	**7.7**	**17,975.7**	**2.4**	**11.0**	**148.0**	**NE**	**1,530.9**	**0.7**	**1,693.1**
Residential Coal	25.4						25.4	2.4						2.4
Commercial Coal		115.5					115.5		11.0					11.0
Industrial Other Coal			1,577.3				1,577.3			148.0				148.0
Transportation Coal				NE										NE
Electric Power Coal					16,249.7		16,249.7					1,530.9		1,530.9
U.S. Territory Coal (bit)						7.7	7.7						0.7	**0.7**
Natural Gas	**4,696.9**	**2,813.2**	**7,942.7**	**620.3**	**3,398.8**	**-**	**19,471.9**	**249.2**	**149.3**	**421.4**	**32.9**	**180.3**		**1,033.1**
Total Petroleum	**1,386.6**	**892.1**	**3,667.5**	**19,560.2**	**1,198.3**	**425.4**	**27,130.1**	**97.5**	**65.6**	**266.9**	**1,400.3**	**94.6**	**31.3**	**1,956.2**
Asphalt & Road Oil														
Aviation Gasoline				41.7			41.7				2.9			2.9
Distillate Fuel Oil	924.8	514.3	1,064.4	3,466.5	83.6	71.4	6,124.9	67.6	37.6	77.9	253.6	6.1	5.2	448.0
Jet Fuel				2,378.1	NA	78.2	2,456.3				169.2		5.6	174.7
Kerosene	72.3	12.1	11.4			2.8	98.6	5.2	0.9	0.8			0.2	7.1
LPG	389.5	68.7	371.4	19.9		13.8	863.3	24.6	4.3	23.4	1.3		0.9	54.5
Lubricants														
Motor Gasoline		85.1	193.3	13,429.6		124.7	13,832.6		6.1	13.8	955.8		8.9	984.5
Residual Fuel		211.9	270.9	224.4	1,085.3	134.6	1,927.2		16.7	21.3	17.7	85.5	10.6	151.9
Other Petroleum														
AvGas Blend Components			(0.1)				(0.1)			(0.0)				(0.0)
Crude Oil			38.9				38.9			2.9				2.9
MoGas Blend Components			(25.9)				(25.9)			(1.8)				(1.8)
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			249.2				249.2			16.7				16.7
Petroleum Coke			539.6		29.3		569.0			55.1		3.0		58.1
Still Gas			1,404.5				1,404.5			90.2				90.2
Special Naphtha														
Unfinished Oils			(450.2)				(450.2)			(33.3)				(33.3)
Waxes														
Geothermal					**54.5**		**54.5**					**0.4**		**0.4**
TOTAL (All Fuels)	**6,108.8**	**3,820.7**	**13,187.5**	**20,180.5**	**20,901.3**	**433.2**	**64,632.1**	**349.1**	**225.9**	**836.3**	**1,433.3**	**1,806.3**	**32.0**	**4,682.9**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-25: 1990 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Adjusted Consumption (TBtu)[a]							Emissions[b] (Tg CO_2 Eq.) from Energy Use						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Elec.**	**Terr.**	**Total**
Total Coal	**31.1**	**124.5**	**1,624.0**	**NE**	**16,261.0**	**7.0**	**18,047.5**	**3.0**	**11.8**	**152.3**	**NE**	**1,531.3**	**0.6**	**1,699.0**
Residential Coal	31.1						31.1	3.0						3.0
Commercial Coal		124.5					124.5		11.8					11.8
Industrial Other Coal			1,624.0				1,624.0			152.3				152.3
Transportation Coal				NE										NE
Electric Power Coal					16,261.0		16,261.0					1,531.3		1,531.3
U.S. Territory Coal (bit)						7.0	7.0						0.6	0.6
Natural Gas	**4,523.1**	**2,701.4**	**7,826.8**	**679.9**	**3,332.2**	**-**	**19,063.4**	**240.0**	**143.3**	**415.3**	**36.1**	**176.8**		**1,011.4**
Total Petroleum	**1,382.3**	**939.6**	**3,974.2**	**19,936.4**	**1,289.4**	**374.8**	**27,896.7**	**97.4**	**69.2**	**289.5**	**1,427.9**	**101.8**	**27.6**	**2,013.3**
Asphalt & Road Oil														
Aviation Gasoline				45.0			45.0				3.1			3.1
Distillate Fuel Oil	953.4	522.3	1,114.4	3,570.5	96.5	74.0	6,331.1	69.7	38.2	81.5	261.2	7.1	5.4	463.1
Jet Fuel				2,486.6	NA	61.0	2,547.6				176.9		4.3	181.2
Kerosene	63.9	11.8	12.3			2.6	90.6	4.6	0.9	0.9			0.2	6.6
LPG	365.0	64.4	406.4	21.6		14.4	871.9	23.0	4.1	25.7	1.4		0.9	55.0
Lubricants														
Motor Gasoline		111.2	185.2	13,512.4		101.0	13,909.8		7.9	13.2	961.7		7.2	990.0
Residual Fuel		229.8	364.2	300.3	1,162.6	121.8	2,178.7		18.1	28.7	23.7	91.6	9.6	171.7
Other Petroleum														
AvGas Blend Components			0.2				0.2			0.0				0.0
Crude Oil			50.9				50.9			3.8				3.8
MoGas Blend Components			53.7				53.7			3.8				3.8
Misc. Products														
Naphtha (<401 deg. F)														
Other Oil (>401 deg. F)														
Pentanes Plus			167.8				167.8			11.2				11.2
Petroleum Coke			536.2		30.4		566.6			54.8		3.1		57.9
Still Gas			1,451.9				1,451.9			93.2				93.2
Special Naphtha														
Unfinished Oils			(369.0)				(369.0)			(27.3)				(27.3)
Waxes														
Geothermal					**52.7**		**52.7**					**0.4**		**0.4**
TOTAL (All Fuels)	**5,936.5**	**3,765.4**	**13,425.0**	**20,616.3**	**20,935.3**	**381.9**	**65,060.3**	**340.3**	**224.3**	**857.1**	**1,464.0**	**1,810.2**	**28.3**	**4,724.1**

[a] Expressed as gross calorific values (i.e., higher heating values). Adjustments include biofuels, conversion of fossil fuels, non-energy use (see Table A-26), and international bunker fuel consumption (see Table A-27).
[b] Consumption and/or emissions of select fuels are shown as negative due to differences in EIA energy balancing accounting. These are designated with parentheses.
NE (Not Estimated)

Table A-26: Unadjusted Non-Energy Fuel Consumption (TBtu)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Industry	**4,537**	**4,560**	**4,676**	**4,844**	**5,162**	**5,222**	**5,293**	**5,513**	**5,744**	**6,013**	**5,633**	**5,287**	**5,387**	**5,340**	**5,872**	**5,571**
Industrial Coking Coal	0	0	0	0	10	44	26	0	8	46	63	25	46	72	215	137
Industrial Other Coal	8	8	10	10	11	11	11	11	10	11	12	11	12	12	12	12
Natural Gas to Chemical Plants, Other Uses	302	301	259	292	354	357	360	385	427	438	440	413	380	380	380	380
Asphalt & Road Oil	1,170	1,077	1,102	1,149	1,173	1,178	1,176	1,224	1,263	1,324	1,276	1,257	1,240	1,220	1,304	1,323
LPG	1,201	1,378	1,391	1,351	1,546	1,587	1,652	1,670	1,744	1,821	1,665	1,553	1,620	1,545	1,576	1,488
Lubricants	186	167	170	173	181	178	173	182	191	193	190	174	172	159	161	160
Pentanes Plus	83	45	62	276	258	303	316	299	204	261	237	202	171	169	170	150
Naphtha (<401 deg. F)	348	299	377	351	398	373	479	536	584	502	614	494	583	613	749	699
Other Oil (>401 deg. F)	754	827	815	844	839	801	730	861	819	811	722	662	632	699	779	708
Still Gas	21	22	11	28	22	40	0	2	0	16	13	36	58	59	64	68
Petroleum Coke	178	153	231	124	136	133	148	118	214	284	141	208	192	163	254	229
Special Naphtha	107	88	105	105	81	71	75	72	107	145	97	78	102	80	51	63
Other (Wax/Misc.)																
Distillate Fuel Oil	7	7	7	7	7	8	9	10	12	12	12	12	12	12	12	12
Waxes	33	35	37	40	41	41	49	44	42	37	33	36	32	31	31	31
Miscellaneous Products	138	153	100	95	106	97	89	98	119	112	119	125	134	126	113	113
Transportation	**176**	**157**	**161**	**163**	**171**	**168**	**163**	**172**	**180**	**182**	**179**	**164**	**162**	**150**	**152**	**151**
Lubricants	176	157	161	163	171	168	163	172	180	182	179	164	162	150	152	151
U.S. Territories	**87**	**114**	**63**	**74**	**55**	**91**	**121**	**132**	**135**	**139**	**165**	**80**	**139**	**128**	**137**	**132**
Lubricants	1	1	1	3	2	2	1	2	1	1	16	0	1	9	10	10
Other Petroleum (Misc. Prod.)	86	114	61	71	53	89	120	129	134	138	149	80	137	119	127	123
Total	**4,800**	**4,831**	**4,899**	**5,082**	**5,388**	**5,481**	**5,577**	**5,817**	**6,060**	**6,335**	**5,978**	**5,531**	**5,688**	**5,618**	**6,160**	**5,855**

Note: These values are unadjusted non-energy fuel use provided by EIA. They have not yet been adjusted to remove petroleum feedstock exports and processes accounted for in the Industrial Processes Chapter.

Table A-27: International Bunker Fuel Consumption (TBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Marine Residual Fuel Oil	716	802	670	534	524	523	536	575	595	490	444	426	290	239	354	347
Marine Distillate Fuel Oil & Other	158	149	146	147	121	126	114	126	159	114	86	72	70	83	97	99
Aviation Jet Fuel	643	647	653	661	670	708	728	780	791	821	844	828	862	830	878	883
Total	**1,517**	**1,598**	**1,468**	**1,342**	**1,315**	**1,357**	**1,379**	**1,481**	**1,544**	**1,424**	**1,374**	**1,327**	**1,222**	**1,151**	**1,328**	**1,329**

Table A-28: Key Assumptions for Estimating CO_2 Emissions

Fuel Type	C Content Coefficient (Tg C/QBtu)
Coal	
Residential Coal	[a]
Commercial Coal	[a]
Industrial Coking Coal	31.00
Industrial Other Coal	[a]
Electric Power Coal	[a]
U.S. Territory Coal (bit)	25.14
Natural Gas	**14.47**
Petroleum	
Asphalt & Road Oil	20.62
Aviation Gasoline	18.87
Distillate Fuel Oil	19.95
Jet Fuel	[a]
Kerosene	19.72
LPG (energy use)	[a]
LPG (non-energy use)	[a]
Lubricants	20.24
Motor Gasoline	[a]
Residual Fuel Oil	21.49
Other Petroleum	
AvGas Blend Components	18.87
Crude Oil	[a]
MoGas Blend Components	[a]
Misc. Products	[a]
Misc. Products (Territories)	20.00
Naphtha (<401 deg. F)	18.14
Other Oil (>401 deg. F)	19.95
Pentanes Plus	18.24
Petrochemical Feedstocks	19.37
Petroleum Coke	27.85
Still Gas	17.51
Special Naphtha	19.86
Unfinished Oils	[a]
Waxes	19.81
Geothermal	**2.05**

Sources: C coefficients from EIA (2006b).
[a] These coefficients vary annually due to fluctuations in fuel quality (see Table A-29).

Table A-29: Annually Variable C Content Coefficients by Year (Tg C/QBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Residential Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Commercial Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Industrial Other Coal	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
Electric Power Coal	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76
LPG (energy use)	17.21	17.21	17.21	17.22	17.22	17.20	17.20	17.18	17.23	17.25	17.20	17.21	17.20	17.21	17.20	17.19
LPG (non-energy use)	16.83	16.84	16.84	16.80	16.88	16.87	16.86	16.88	16.88	16.84	16.81	16.83	16.82	16.84	16.81	16.81
Motor Gasoline	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.33	19.33	19.34	19.34	19.35	19.33	19.33	19.33
Jet Fuel	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33
MoGas Blend Components	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.33	19.33	19.34	19.34	19.35	19.33	19.33	19.33
Misc. Products	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33
Unfinished Oils	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33
Crude Oil	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33

Source: EIA (2006b)

Table A-30: Electricity Consumption by End-Use Sector (Billion Kilowatt-Hours)

End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Residential	924	955	936	995	1,008	1,043	1,083	1,076	1,130	1,145	1,192	1,201	1,265	1,274	1,294	1,361
Commercial	838	855	850	885	913	953	980	1,027	1,078	1,104	1,159	1,191	1,205	1,197	1,229	1,267
Industrial	1,070	1,071	1,107	1,116	1,154	1,163	1,186	1,194	1,212	1,230	1,235	1,147	1,156	1,180	1,187	1,177
Transportation	5	5	5	5	5	5	5	5	5	5	5	5	5	7	7	8
Total	**2,837**	**2,886**	**2,897**	**3,001**	**3,081**	**3,164**	**3,254**	**3,302**	**3,425**	**3,484**	**3,592**	**3,545**	**3,632**	**3,658**	**3,717**	**3,813**

Note: Does not include the U.S. territories.
Source: EIA (2006a)

2.2. Methodology for Estimating the Carbon Content of Fossil Fuels

This subannex presents the background and methodology for estimating the carbon (C) content of fossil fuels combusted in the United States. The C content of a particular fossil fuel represents the maximum potential emissions to the atmosphere if all C in the fuel is oxidized during combustion. The C content coefficients used in this report were developed using methods first outlined in EIA's *Emissions of Greenhouse Gases in the United States: 1987-1992* (1994) and were developed primarily by EIA. This annex describes an updated methodology for estimating the C content of coal, and presents a time-series analysis of changes in U.S. C content coefficients. A summary of C content coefficients used in this report appears in Table A-31.

Though the methods for estimating C contents for coal, natural gas, and petroleum products differ in their details, they each follow the same basic approach. First, because C coefficients are presented in terms of mass per unit energy (i.e., teragrams C per quadrillion Btu or Tg C/QBtu), those fuels that are typically described in volumetric units (petroleum products and natural gas) are converted to units of mass using an estimated density. Second, C contents are derived from fuel sample data, using descriptive statistics to estimate the C share of the fuel by weight. The heat content of the fuel is then estimated based on the sample data, or where sample data are unavailable or unrepresentative, by default values that reflect the characteristics of the fuel as defined by market requirements. A discussion of each fuel appears below.

The C content of coal is described first because approximately one-third of all U.S. C emissions from fossil fuel combustion are associated with coal consumption. The methods and sources for estimating the C content of natural gas are provided next. Approximately one-fifth of U.S. greenhouse gas emissions from fossil fuel combustion are attributable to natural gas consumption. Finally, this subannex examines C contents of petroleum products. U.S. energy consumption statistics account for more than 20 different petroleum products.

Table A-31: Carbon Content Coefficients Used in this Report (Tg Carbon/QBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Coal																
Residential Coal[a]	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Commercial Coal[a]	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Industrial Coking Coal[a]	25.51	25.51	25.51	25.51	25.52	25.53	25.55	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56
Industrial Other Coal[a]	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
Utility Coal[a,b]	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76
Natural Gas	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**	**14.47**
Petroleum																
Asphalt and Road Oil	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62	20.62
Aviation Gasoline	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87
Distillate Fuel Oil	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95
Jet Fuel[a]	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33	19.33
Kerosene	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72
LPG (energy use)[a]	17.21	17.21	17.21	17.22	17.22	17.20	17.20	17.18	17.23	17.25	17.20	17.21	17.20	17.21	17.20	17.19
LPG (non-energy use)[a]	16.83	16.84	16.84	16.80	16.88	16.87	16.86	16.88	16.88	16.84	16.81	16.83	16.82	16.84	16.81	16.81
Lubricants	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24	20.24
Motor Gasoline[a]	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.33	19.33	19.34	19.34	19.35	19.33	19.33	19.33
Residual Fuel	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49
Other Petroleum																
Av Gas Blend Comp.	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87	18.87
Mo Gas Blend Comp[a]	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35	19.33	19.33	19.34	19.34	19.35	19.33	19.33	19.33
Crude Oil[a]	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33
Misc. Products[a]	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33
Misc. Products (Terr.)	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Naphtha (<401 deg. F)	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14	18.14
Other oil (>401 deg. F)	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95	19.95
Pentanes Plus	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24	18.24
Petrochemical Feed.	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37	19.37
Petroleum Coke	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85
Still Gas	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51
Special Naphtha	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86	19.86
Unfinished Oils[a]	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24	20.24	20.19	20.23	20.29	20.30	20.28	20.33	20.33
Waxes	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81
Other Wax and Misc.	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81	19.81
Geothermal	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**	**2.05**

[a] C contents vary annually based on changes in fuel composition.

[b] C content for utility coal used in the electric power calculations. All coefficients based on higher heating value. Higher heating value (gross heating value) is the total amount of heat released when a fuel is burned. Coal, crude oil, and natural gas all include chemical compounds of carbon and hydrogen. When those fuels are burned, the carbon and hydrogen combine with oxygen in the air to produce CO2 and water. Some of the energy released in burning goes into transforming the water into steam and is usually lost. The amount of heat spent in transforming the water into steam is counted as part of gross heat content. Lower heating value (net heating value), in contrast, does not include the heat spent in transforming the water into steam. Using a simplified methodology based on International Energy Agency defaults, higher heating value can be converted to lower heating value for coal and petroleum products by multiplying by 0.95 and for natural gas by multiplying by 0.90. Carbon content coefficients are presented in higher heating value because U.S. energy statistics are reported by higher heating value.

Coal

Approximately one-third of all U.S. CO_2 emissions from fossil fuel combustion are associated with coal consumption. Although the IPCC guidelines provide C contents for coal according to rank, it was necessary to develop C content coefficients by consuming sector to match the format in which coal consumption is reported by EIA. Because the C content of coal varies by the state in which it was mined and by coal rank, and because the sources of coal for each consuming sector vary by year, the weighted average C content for coal combusted in each consuming sector also varies over time. A time series of C contents by coal rank and consuming sector appears in Table A-32.[1]

Methodology

The methodology for developing C contents for coal by consuming sector consists of four steps.

Step 1. Determine carbon contents by rank and by state of origin

C contents by rank are estimated on the basis of 6,588 coal samples collected by the U.S. Geological Survey between 1973 and 1989. These coal samples are classified according to rank and state of origin. For each rank in each state, the average heat content and C content of the coal samples are calculated. Dividing the C content (reported in pounds CO_2) by the heat content (reported in million Btu or MMBtu) yields an average C content coefficient. This coefficient is then converted into units of Tg C/QBtu.

Step 2. Allocate sectoral consumption by rank and state of origin

U.S. energy statistics provide data on the origin of coal used in four areas: 1) the electric power industry, 2) industrial coking, 3) all other industrial uses, and 4) the residential and commercial end-use sectors. Because U.S. energy statistics do not provide the distribution of coal rank consumed by each consuming sector, it is assumed that each sector consumes a representative mixture of coal ranks from a particular state that matches the mixture of all coal produced in that state during the year.

Step 3. Weight sectoral carbon contents to reflect the rank and state of origin of coal consumed

Sectoral C contents are calculated by multiplying the share of coal purchased from each state by rank by the C content estimated in Step 1. The resulting partial C contents are then totaled across all states and ranks to generate a national sectoral C content.

$$C_{sector} = S_{rank1} \times C_{rank1} + S_{rank2} \times C_{rank2} + \ldots + S_{rank50} \times C_{rank50}$$

Where,

C_{sector} = The C content by consuming sector;
S_{rank} = The portion of consuming sector coal consumption attributed to a given rank in each state;
C_{rank} = The estimated C content of a given rank in each state.

[1] For a comparison to earlier estimated carbon contents please see *Chronology and Explanation of Changes in Individual Carbon Content Coefficients of Fossil Fuels* near the end of this annex.

Table A-32: Carbon Content Coefficients for Coal by Consuming Sector and Coal Rank (Tg C/QBtu) (1990-2005)

Consuming Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Electric Power	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76
Industrial Coking	25.51	25.51	25.51	25.51	25.52	25.53	25.55	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56
Other Industrial	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
Residential/ Commercial	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Coal Rank																
Anthracite	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26 [p]
Bituminous	25.43	25.45	25.44	25.45	25.46	25.47	25.47	25.48	25.47	25.48	25.49	25.49	25.49	25.49	25.49	25.49 [p]
Sub-bituminous	26.50	26.49	26.49	26.48	26.49	26.49	26.49	26.49	26.49	26.49	26.48	26.48	26.48	26.48	26.48	26.48 [p]
Lignite	26.19	26.21	26.22	26.21	26.24	26.22	26.17	26.20	26.23	26.26	26.30	26.30	26.30	26.30	26.30	26.30 [p]

[p] Preliminary

Sources: C content coefficients by consuming sector from EIA (2006a). C content coefficients by coal rank from USGS (1998) and SAIC (2005).

Step 4. Develop national-level carbon contents by rank for comparison to IPCC defaults

Although not used to calculate emissions, national-level C contents by rank are more easily compared to C contents of other countries than are sectoral C contents. This step requires weighting the state-level C contents by rank developed under Step 1 by overall coal production by state and rank (consumption by rank is unavailable in U.S. energy statistics). Each state-level C content by rank is multiplied by the share of national production of that rank that each state represents. The resulting partial C contents are then summed across all states to generate an overall C content for each rank.

$$N_{rank} = P_{rank1} \times C_{rank1} + P_{rank2} \times C_{rank2} + \ldots + P_{rankn} \times C_{rankn}$$

Where,

N_{rank} = The national C content by rank;
P_{rank} = The portion of U.S. coal production attributed to a given rank in each state; and
C_{rank} = The estimated C content of a given rank in each state.

Data Sources

The ultimate analysis of coal samples was based on the 6,588 coal samples from USGS (1998). Data contained in the CoalQual Database are derived primarily from samples taken between 1973 and 1989, and were largely reported in State Geological Surveys.

Data on coal distribution by state and consumption by sector, as well as coal production by state and rank, was obtained from EIA (2002).

Uncertainty

C contents vary considerably by state. Bituminous coal production and sub-bituminous coal production represented 53.4 percent and 38.1 percent of total U.S. supply in 2000, respectively. C content coefficients for bituminous coal vary from a low of 90.94 kg CO2 per MMBtu in Kansas to a high of 105.23 kg CO2 per MMBtu in Montana. In 2000, however, just 200 tons of bituminous coal was produced in Kansas, and none was produced in Montana. In 2000, more than 60 percent of bituminous coal was produced in three states: West Virginia, Kentucky, and Pennsylvania, and this share has remained fairly constant since 1990. These three states show a variation in C content for bituminous coals of ±0.7 percent, based on more than 2,000 samples (see Table A-33).

Similarly, the C content coefficients for sub-bituminous coal range from 91.31 kg CO2 per MMBtu in Utah to 98.66 kg CO2 per MMBtu in Washington. Utah showed no sub-bituminous coal production in 2000, and Washington produced just 4,000 tons. Wyoming, however, has represented between 75 percent and 82 percent of total sub-bituminous coal production in the United States since 1990. Thus, the C content coefficient for Wyoming, based on 435 samples, dominates.

The interquartile range of C content coefficients among samples of sub-bituminous coal in Wyoming was ±1.5 percent from the mean. Similarly, this range among samples of bituminous coal from West Virginia, Kentucky, and Pennsylvania was ±1.0 percent or less for each state. The large number of samples and the low variability within the sample set of the states that represent the predominant source of supply for U.S. coal suggest that the uncertainty in this factor is very low, on the order of ±1.0 percent.

Table A-33: Variability in Carbon Content Coefficients by Rank Across States (Kilograms CO2 Per MMBtu)

State	Number of Samples	Bituminous	Sub-bituminous	Anthracite	Lignite
Alabama	946	92.85	-	-	99.11
Alaska	90	98.34	98.11	-	98.66
Arizona	11	-	97.52	-	-
Arkansas	70	96.52	-	-	94.98
Colorado	292	94.39	96.48	-	96.48
Georgia	35	95.03	-	-	-
Idaho	1	-	94.89	-	-
Illinois	16	93.35	-	-	-
Indiana	125	92.67	-	-	-

Iowa	89	91.94	-	-	-
Kansas	28	90.94	-	-	-
Kentucky	870	92.58	-	-	-
Louisiana	1	-	-	-	96.03
Maryland	46	94.35	-	-	-
Massachusetts	3	-	-	114.82	-
Michigan	3	92.85	-	-	-
Mississippi	8	-	-	-	98.20
Missouri	91	91.85	-	-	-
Montana	301	105.23	97.75	103.60	99.38
Nevada	2	94.39	-	-	99.84
New Mexico	167	95.25	94.89	103.92	-
North Dakota	186	-	-	-	99.56
Ohio	646	91.85	-	-	-
Oklahoma	46	92.67	-	-	-
Pennsylvania	739	93.39	-	103.65	-
Tennessee	58	92.80	-	-	-
Texas	48	-	-	-	94.76
Utah	152	96.07	91.31	-	-
Virginia	456	93.53	-	98.52	-
Washington	14	95.39	98.66	102.51	106.55
West Virginia	566	93.89	-	-	-
Wyoming	476	94.66	97.20	-	-

- No Sample Data Available

Sources: USGS (1998) and SAIC (2005).

Natural Gas

Natural gas is predominantly composed of methane, which is 75 percent C by weight and contains 14.2 Tg C/QBtu (Higher Heating Value), but it may also contain many other compounds that can lower or raise its overall C content. These other compounds may be divided into two classes: 1) natural gas liquids (NGLs), and 2) non-hydrocarbon gases. The most common NGLs are ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and, to a lesser extent, pentane (C_5H_{12}) and hexane (C_6H_{14}). Because the NGLs have more C atoms than methane (which has only one), their presence increases the overall C content of natural gas. NGLs have a commercial value greater than that of methane, and therefore are usually separated from raw natural gas at gas processing plants and sold as separate products. Ethane is typically used as a petrochemical feedstock, propane and butane have diverse uses, and natural gasoline[1] contributes to the gasoline/naphtha "octane pool," used primarily to make motor gasoline.

Raw natural gas can also contain varying amounts of non-hydrocarbon gases, such as CO2, nitrogen, helium and other noble gases, and hydrogen sulfide. The share of non-hydrocarbon gases is usually less than 5 percent of the total, but there are individual natural gas reservoirs where the share can be much larger. The treatment of non-hydrocarbon gases in raw gas varies. Hydrogen sulfide is always removed. Inert gases are removed if their presence is substantial enough to reduce the energy content of the gas below pipeline specifications. Otherwise, inert gases will usually be left in the natural gas. Because the raw gas that is usually flared contains NGLs and CO2, it will typically have a higher overall C content than gas that has been processed and moved to end-use customers via transmission and distribution pipelines.

Methodology

The methodology for estimating the C contents of natural gas can be described in five steps.

Step 1. Define pipeline-quality natural gas

In the United States, pipeline-quality natural gas is expected to have an energy content greater than 970 Btu per cubic foot, but less than 1,100 Btu per cubic foot. Hydrogen sulfide content must be negligible. Typical pipeline-quality natural gas is about 95 percent methane, 3 percent NGLs, and 2 percent non-hydrocarbon gases, of which approximately 1 percent is CO2.

1 A term used in the gas processing industry to refer to a mixture of liquid hydrocarbons (mostly pentanes and heavier hydrocarbons) extracted from natural gas.

However, there is a range of gas compositions that are consistent with pipeline specifications. The minimum C content coefficient for natural gas would match that for pure methane, which equates to an energy content of 1,005 Btu per standard cubic foot. Gas compositions with higher or lower Btu content tend to have higher C emission factors, because the "low" Btu gas has a higher content of inert gases (including CO2 offset with more NGLs), while "high" Btu gas tends to have more NGLs.

Step 2. Define flared gas

Every year, a certain amount of natural gas is flared in the United States. There are several reasons that gas is flared:

- There may be no market for some batches of natural gas, the amount may be too small or too variable, or the quality might be too poor to justify treating the gas and transporting it to market (such is the case when gas contains large shares of CO2). All natural gas flared for these reasons is probably "rich" associated gas, with relatively high energy content, high NGL content, and a high C content.

- Gas treatment plants may flare substantial volumes of natural gas because of "process upsets," because the gas is "off spec," or possibly as part of an emissions control system. Gas flared at processing plants may be of variable quality.

Data on the energy content of flare gas, as reported by states to EIA, indicate an energy content of 1,130 Btu per standard cubic foot. Flare gas may have an even higher energy content than reported by EIA since rich associated gas can have energy contents as high as 1,300 to 1,400 Btu per cubic foot.

Step 3. Determine a relationship between carbon content and heat content

A relationship between C content and heat content may be used to develop a C content coefficient for natural gas consumed in the United States. In 1994, EIA examined the composition (and therefore C contents) of 6,743 samples of pipeline-quality natural gas from utilities and/or pipeline companies in 26 cities located in 19 states. To demonstrate that these samples were representative of actual natural gas "as consumed" in the United States, their heat content was compared to that of the national average. For the most recent year, the average heat content of natural gas consumed in the United States was 1,025 Btu per cubic foot, varying by less than 1 percent (1,025 to 1,031 Btu per cubic foot) over the past 5 years. Meanwhile, the average heat content of the 6,743 samples was 1,027 Btu per cubic foot, and the median heat content was 1,031 Btu per cubic foot. Thus, the average heat content of the sample set falls well within the typical range of natural gas consumed in the United States, suggesting that these samples continue to be representative of natural gas “as consumed” in the United States. The average and median composition of these samples appears in Table A-34.

Table A-34: Composition of Natural Gas (Percent)

Compound	Average	Median
Methane	93.07	95.00
Ethane	3.21	2.79
Propane	0.59	0.48
Higher Hydrocarbons	0.32	0.30
Non-hydrocarbons	2.81	1.43
Higher Heating Value (Btu per cubic foot)	1,027	1,032

Source: Gas Technology Institute (1992)

C contents were then calculated for a series of sub samples stratified by heat content. C contents were developed for eight separate sub-samples based on heat content and are shown in Table A-35.

Table A-35: Carbon Content of Pipeline-Quality Natural Gas by Energy Content (Tg C/QBtu)

Sample	Average Carbon Content
GRI Full Sample	14.51
Greater than 1,000 Btu	14.47
1,025 to 1,035 Btu	14.45
975 to 1,000 Btu	14.73
1,000 to 1,025 Btu	14.43

1,025 to 1,050 Btu	14.47
1,050 to 1,075 Btu	14.58
1,075 to 1,100 Btu	14.65
Greater than 1,100 Btu	14.92
Weighted National Average	14.47

Source: EIA (1994).

Step 4. Apply carbon content coefficients developed in Step 3 to pipeline natural gas

Because there is some regional variation in the energy content of natural gas consumed, a weighted national average C content was calculated using the average C contents for each sub-sample of gas that conformed with an individual state's typical cubic foot of natural gas. The result was a weighted national average of 14.47 Tg C/QBtu. This was identical to the average C content of all samples with more than 1,000 Btu per cubic foot and the average C content for all samples with a heat content between 1,025 and 1,050 Btu per cubic foot. Because those samples with a heat content below 1,000 Btu had an unusually high C content coefficient attributable to large portions of CO2 (not seen in the median sample), they were excluded so as not to bias the C content coefficient upwards by including them in the final sample used to select a C content.

Step 5. Apply carbon content coefficients developed in Step 3 to flare gas

Selecting a C content coefficient for flare gas was much more difficult than for pipeline natural gas because of the uncertainty of its composition and uncertainty of the combustion efficiency of the flare. Because EIA estimates the heat content of flare gas at 1,130 Btu per cubic foot, the average C content for samples with more than 1,100 Btu per cubic foot, 14.92 Tg C/QBtu, was adopted as the coefficient for flare gas. It should be noted that the sample data set did not include any samples with more than 1,130 Btu per cubic foot.

Data Sources

Natural gas samples were obtained from the Gas Technology Institute (1992). Average heat content data for natural gas consumed in the United States and on a state-by-state basis were taken from EIA (2006a) and EIA (2003), respectively.

Uncertainty

The assignment of C content coefficients for natural gas, and particularly for flare gas, requires more subjective judgment than the methodology used for coal. This subjective judgment may introduce additional uncertainty.

Figure A-1 shows the relationship between the calculated C contents for each natural gas sample and its energy content. This figure illustrates the relatively restricted range of variation in both the energy content (which varies by about 6 percent from average) and the C emission coefficient of natural gas (which varies by about 5 percent). Thus, the knowledge that gas has been sold via pipeline to an end-use consumer allows its C emission coefficient to be predicted with an accuracy of ±5.0 percent.

Figure A-1: Carbon Content for Samples of Pipeline-Quality Natural Gas Included in the Gas Technology Institute Database

[Figures are attached at the end of each chapter.]

Source: EIA (1994).

Natural gas suppliers may achieve the same energy contents with a wide variety of methane, higher hydrocarbon, and non-hydrocarbon gas combinations. Thus, the plot reveals large variations in C content for a single Btu value. In fact, the variation in C content for a single Btu value may be nearly as great as the variation for the whole sample. As a result, while energy content has some predictive value, the specific energy content does not substantially improve the accuracy of an estimated C content coefficient beyond the ±5.0 percent offered with the knowledge that it is of pipeline-quality.

The plot of C content also reveals other interesting anomalies. Samples with the lowest emissions coefficients tend to have energy contents of about 1,000 Btu per cubic foot. They are composed of almost pure methane. Samples with a greater proportion of NGLs (e.g., ethane, propane, and butane) tend to have energy contents greater than 1,000 Btu per cubic foot, along with higher emissions coefficients. Samples with a greater proportion of inert gases tend to have lower energy content, but they usually contain carbon dioxide as one of the inert gases and, consequently, also tend to have higher emission coefficients (see left side of Figure A-1).

For the full sample (N=6,743), the average C content of a cubic foot of gas was 14.51 Tg C/QBtu (see Table A-35). However, this average was raised by both the samples with less than 1,000 Btu per cubic foot that contain large amounts of inert carbon dioxide and those samples with more than 1,050 Btu per cubic foot that contain an unusually large amount of NGLs. Because typical gas consumed in the United States does not contain such a large amount of carbon dioxide or natural gas liquids, a weighted national average of 14.47 Tg C/QBtu that represents fuels more typically consumed is used.[2]

Petroleum

There are four critical determinants of the C content coefficient for a petroleum-based fuel:

- The density of the fuel (e.g., the weight in kilograms of one barrel of fuel);
- The fraction by mass of the product that consists of hydrocarbons, and the fraction of non-hydrocarbon impurities;
- The specific types of 'families' of hydrocarbons that make up the hydrocarbon portion of the fuel; and
- The heat content of the fuel.

$$C_{fuel} = (D_{fuel} \times S_{fuel}) / E_{fuel}$$

Where,

C_{fuel} = The C content coefficient of the fuel;
D_{fuel} = The density of the fuel;
S_{fuel} = The share of the fuel that is C; and
E_{fuel} = The heat content of the fuel.

Petroleum products vary between 5.6 degrees API gravity (dense products such as asphalt and road oil) and 247 degrees (ethane).[3] This is a range in density of 60 to 150 kilograms per barrel, or ±50 percent. The variation in C content, however, is much smaller (±5 to 7 percent): ethane is 80 percent C by weight, while petroleum coke is 90 to 92 percent C. The tightly bound range of C contents can be explained by basic petroleum chemistry.

Petroleum Chemistry

Crude oil and petroleum products are typically mixtures of several hundred distinct compounds, predominantly hydrocarbons. All hydrocarbons contain hydrogen and C in various proportions. When crude oil is distilled into petroleum products, it is sorted into fractions by the boiling temperature of these hundreds of organic

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[2] The national average was weighted by applying the carbon content associated with the average heat content of natural gas consumed in each state by the portion of national natural gas consumption represented by that state.

[3] API gravity is an arbitrary scale expressing the gravity or density of liquid petroleum products, as established by the American Petroleum Institute (API). The measuring scale is calibrated in terms of degrees API. The higher the API gravity, the lighter the compound. Light crude oils generally exceed 38 degrees API and heavy crude oils are all crude oils with an API gravity of 22 degrees or below. Intermediate crude oils fall in the range of 22 degrees to 38 degrees API gravity. API gravity can be calculated with the following formula: API Gravity = (141.5/Specific Gravity) – 131.5. Specific gravity is the density of a material relative to that of water. At standard temperature and pressure, there are 62.36 pounds of water per cubic foot, or 8.337 pounds water per gallon.

compounds. Boiling temperature is strongly correlated with the number of C atoms in each molecule. Petroleum products consisting of relatively simple molecules and few C atoms have low boiling temperatures, while larger molecules with more C atoms have higher boiling temperatures.

Products that boil off at higher temperatures are usually more dense, which implies greater C content as well. Petroleum products with higher C contents, in general, have lower energy content per unit mass and higher energy content per unit volume than products with lower C contents. Empirical research led to the establishment of a set of quantitative relationships between density, energy content per unit weight and volume, and C and hydrogen content. Figure A-2 compares C content coefficients calculated on the basis of the derived formula with actual C content coefficients for a range of crude oils, fuel oils, petroleum products, and pure hydrocarbons. The actual fuel samples were drawn from the sources described below in the discussions of individual petroleum products.

Figure A-2: Estimated and Actual Relationships Between Petroleum Carbon Content Coefficients and Hydrocarbon Density

[Figures are attached at the end of each chapter.]

Source: C content factors for paraffins are calculated based on the properties of hydrocarbons in Guthrie (1960). C content factors from other petroleum products are drawn from sources described below. Relationship between density and emission factors based on the relationship between density and energy content in DOC (1929), and relationship between energy content and fuel composition in Ringen et al. (1979).

The derived empirical relationship between C content per unit heat and density is based on the types of hydrocarbons most frequently encountered. Actual petroleum fuels can vary from this relationship due to non-hydrocarbon impurities and variations in molecular structure among classes of hydrocarbons. In the absence of more exact information, this empirical relationship offers a good indication of C content.

Non-hydrocarbon Impurities

Most fuels contain a certain share of non-hydrocarbon material. This is also primarily true of crude oils and fuel oils. The most common impurity is sulfur, which typically accounts for between 0.5 and 4 percent of the mass of most crude oils, and can form an even higher percentage of heavy fuel oils. Some crude oils and fuel oils also contain appreciable quantities of oxygen and nitrogen, typically in the form of asphaltenes or various acids. The nitrogen and oxygen content of crude oils can range from near zero to a few percent by weight. Lighter petroleum products have much lower levels of impurities, because the refining process tends to concentrate all of the non-hydrocarbons in the residual oil fraction. Light products usually contain less than 0.5 percent non-hydrocarbons by mass. Thus, the C content of heavy fuel oils can often be several percent lower than that of lighter fuels, due entirely to the presence of non-hydrocarbons.

Variations in Hydrocarbon Classes

Hydrocarbons can be divided into five general categories, each with a distinctive relationship between density and C content and physical properties. Refiners tend to control the mix of hydrocarbon types in particular products in order to give petroleum products distinct properties. The main classes of hydrocarbons are described below.

*Paraffins***.** Paraffins are the most common constituent of crude oil, usually comprising 60 percent by mass. Paraffins are straight-chain hydrocarbons with the general formula C_nH_{2n+2}. Paraffins include ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and octane (C_8H_{18}). As the chemical formula suggests, the C content of the paraffins increases with their C number: ethane is 80 percent C by weight, octane 84 percent. As the size of paraffin molecules increases, the C content approaches the limiting value of 85.7 percent asymptotically (see Figure A- 3).

Cycloparaffins. Cycloparaffins are similar to paraffins, except that the C molecules form ring structures rather than straight chains, and consequently require two fewer hydrogen molecules than paraffins. Cycloparaffins always have the general formula C_nH_{2n} and are 85.7 percent C by mass, regardless of molecular size.

Olefins. Olefins are a reactive and unstable form of paraffin: a straight chain with the two hydrogen atoms at each end of the chain missing. They are never found in crude oil but are created in moderate quantities by the refining process. Thus, gasoline, for example, may contain 2 percent olefins. They also have the general formula C_nH_{2n}, and hence are also always 85.7 percent C by weight. Propylene (C_3H_6), a common intermediate petrochemical product, is an olefin.

Aromatics. Aromatics are very reactive hydrocarbons that are relatively uncommon in crude oil (10 percent or less). Light aromatics increase the octane level in gasoline, and consequently are deliberately created by steam reforming of naphtha. Aromatics also take the form of ring structures with some double bonds between C atoms. The most common aromatics are benzene (C_6H_6), toluene (C_7H_8), and xylene (C_8H_{10}). The general formula for aromatics is C_nH_{2n-6}. Benzene is 92 percent C by mass, while xylene is 90.6 percent C by mass. Unlike the other hydrocarbon families, the C content of aromatics declines asymptotically toward 85.7 percent with increasing C number and density (see Figure A- 3)

Polynuclear Aromatics. Polynuclear aromatics are large molecules with a multiple ring structure and few hydrogen atoms, such as naphthalene ($C_{10}H_2$ and 94.4 percent C by mass) and anthracene ($C_{14}H_4$ and 97.7 percent C). They are relatively rare but do appear in heavier petroleum products.

Figure A- 3 illustrates the share of C by weight for each class of hydrocarbon. Hydrocarbon molecules containing 2 to 4 C atoms are all natural gas liquids; hydrocarbons with 5 to 10 C atoms are predominantly found in naphtha and gasoline; and hydrocarbon compounds with 12 to 20 C atoms comprise "middle distillates," which are used to make diesel fuel, kerosene and jet fuel. Larger molecules are generally used as lubricants, waxes, and residual fuel oil.

Figure A- 3: Carbon Content of Pure Hydrocarbons as a Function of Carbon Number

[Figures are attached at the end of each chapter.]

Source: Hunt (1979).

If one knows nothing about the composition of a particular petroleum product, assuming that it is 85.7 percent C by mass is not an unreasonable first approximation. Since denser products have higher C numbers, this guess would be most likely to be correct for crude oils and fuel oils. The C content of lighter products is more affected by the shares of paraffins and aromatics in the blend.

Energy Content of Petroleum Products

The exact energy content (gross heat of combustion) of petroleum products is not generally known. EIA estimates energy consumption in Btu on the basis of a set of industry-standard conversion factors. These conversion factors are generally accurate to within 3 to 5 percent.

Individual Petroleum Products

The United States maintains data on the consumption of more than 20 separate petroleum products and product categories. The C contents, heat contents, and density for each product are provided below in Table A-36. A description of the methods and data sources for estimating the key parameters for each individual petroleum product appears below.

Table A-36: Carbon Content Coefficients and Underlying Data for Petroleum Products

Fuel	2005 Carbon Content (Tg C/QBtu)	Gross Heat of Combustion (MMBtu/Barrel)	Density (API Gravity)	Percent Carbon
Motor Gasoline	19.33	5.218	59.6	86.60
LPG(total)	16.99	a	a	a

LPG (energy use)	17.19	a	a	a
LPG (non-energy use)	16.81	a	a	a
Jet Fuel	19.33	5.670	42.0	86.30
Distillate Fuel	19.95	5.825	35.5	86.34
Residual Fuel	21.49	6.287	11.0	85.68
Asphalt and Road Oil	20.62	6.636	5.6	83.47
Lubricants	20.24	6.065	25.6	85.80
Petrochemical Feedstocks	19.37	5.248 [b]	67.1 [b]	84.11 [b]
Aviation Gas	18.87	5.048	69.0	85.00
Kerosene	19.72	5.670	41.4	86.01
Petroleum Coke	27.85	6.024	-	92.28
Special Naphtha	19.86	5.248	51.2	84.76
Petroleum Waxes	19.81	5.537	43.3	85.29
Still Gas	17.51	6.000	-	-
Crude Oil	20.33	5.800	30.5	85.49
Unfinished Oils	20.33	5.825	30.5	85.49
Miscellaneous Products	20.33	5.796	30.5	85.49
Pentanes Plus	18.24	4.620	81.7	83.70
Natural Gasoline	18.24	4.620	81.7	83.70

[a] LPG is a blend of multiple paraffinic hydrocarbons: ethane, propane, isobutane, and normal butane, each with their own heat content, density and C content, see Table A-39.
[b] Parameters presented are for naphthas with a boiling temperature less than 400 degrees Fahrenheit. Petrochemical feedstocks with higher boiling points are assumed to have the same characteristics as distillate fuel.
- No sample data available
Sources: EIA (1994), EIA (2006a), and SAIC (2005).

Motor Gasoline and Motor Gasoline Blending Components

Motor gasoline is a complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines.[4] "Motor Gasoline" includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline; but excludes aviation gasoline.

Gasoline is the most widely used petroleum product in the United States, and its combustion accounts for nearly 20 percent of all U.S. CO_2 emissions. EIA collects consumption data (i.e., "petroleum products supplied" by wholesalers) for several types of gasoline: leaded regular, unleaded regular, and unleaded high octane. The American Society for Testing and Materials (ASTM) standards permit a broad range of densities for gasoline, ranging from 50 to 70 degrees API gravity, or 111.52 to 112.65 kilograms per barrel, which implies a range of possible C and energy contents per barrel. Table A-37 reflects changes in the density of gasoline over time and across grades of gasoline through 2005.

Table A-37: Motor Gasoline Density, 1990 – 2005 (Degrees API)

Fuel Grade	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Winter Grade																
Low Octane	62.0	61.8	61.4	61.0	60.1	59.8	60.6	61.5	61.8	61.6	61.6	61.7	61.6	61.8	62.4	62.4
Mid Octane	60.8	60.4	60.2	59.9	59.4	59.1	59.9	60.7	61.2	61.3	61.2	61.2	61.2	61.2	61.2	61.2
High Octane	59.0	59.3	59.0	58.7	58.5	58.0	58.5	59.3	60.0	60.3	59.7	59.1	59.0	59.9	60.7	60.7
Summer Grade																
Low Octane	58.2	58.0	57.4	56.1	55.7	56.1	56.9	57.1	57.6	57.7	56.8	57.2	56.5	56.8	57.4	57.4
Mid Octane	57.4	57.1	56.4	55.5	54.8	55.6	56.2	56.6	56.7	57.4	58.0	58.0	58.0	58.0	58.0	58.0
High Octane	55.5	55.7	55.6	54.4	53.8	55.1	55.3	56.4	55.7	57.4	55.8	55.5	55.7	56.0	57.0	57.0

Source: National Institute of Petroleum and Energy Research (1990 through 2005).

The density of motor gasoline increased across all grades through 1994, partly as a result of the leaded gasoline phase-out. In order to maintain the "anti-knock" quality and octane ratings of gasoline in the absence of lead, the portion of aromatic hydrocarbons used in gasoline increased. As discussed above, aromatic hydrocarbons

[4] Motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 degrees to 158 degrees Fahrenheit at the 10-percent recovery point to 365 degrees to 374 degrees Fahrenheit at the 90-percent recovery point.

have a lower ratio of hydrogen to C than other hydrocarbons typically found in gasoline, and therefore increase fuel density.

The trend in gasoline density was reversed beginning in 1996 with the development of fuel additives that raised oxygen content. In 1995, a requirement for reformulated gasoline in non-attainment areas implemented under the Clean Air Act Amendments further changed the composition of gasoline consumed in the United States. In reformulated gasoline, methyl tertiary butyl ether (MTBE) and tertiary amyl methyl ether (TAME) are often added to standard gasoline to boost its oxygen content. The increased oxygen reduces the emissions of carbon monoxide and unburned hydrocarbons. These oxygen-rich blending components are also much lower in C than standard gasoline. The average gallon of reformulated gasoline consumed in 2001 contained 8 percent MTBE and 0.5 percent TAME. The characteristics of reformulated fuel additives appear in Table A-38.

Table A-38: Characteristics of Major Reformulated Fuel Additives

Additive	Density (Degrees API)	Carbon Share (Percent)	Carbon Content (Tg C/QBtu)
MTBE	59.1	68.2	16.92
ETBE	59.1	70.5	17.07
TAME	52.8	70.5	17.00

Source: API (1988).

Methodology

Step 1. Disaggregate U.S. gasoline consumption by grade and type

U.S. gasoline consumption was divided by product grade and season for both standard gasoline and reformulated gasoline.

Step 2. Develop carbon content coefficients for each grade and type

C content coefficients for each grade and type are derived from three parameters: gasoline density, share of the gasoline mixture that is C; and the energy content of a gallon of gasoline. C content coefficients for reformulated fuels were calculated by applying the C content coefficient for the fuel additives listed in Table A-38 to the increased share of reformulated gasoline represented by these additives (standard gasoline contains small amounts of MTBE and TAME) and weighting the gasoline C content accordingly.

Step 3. Weight overall gasoline carbon content coefficient for consumption of each grade and type

The C content for each grade and type of fuel is multiplied by the share of overall consumption represented by the grade and fuel type. Individual coefficients are then summed and totaled to yield an overall C content coefficient.

Data Sources

Data for the density of motor gasoline were obtained from the National Institute for Petroleum and Energy Research (1990 through 2005). Data on the characteristics of reformulated gasoline were taken from API (1988). C contents of motor gasoline were obtained from the following: DeLuchi (1993), Applied Systems Corporation (1976), Ward, C.C. (1978), and Rose and Cooper (1977).

Standard heat contents for motor gasoline of 5.253 MMBtu per barrel conventional gasoline and 5.150 MMBtu per barrel reformulated gasoline were adopted from EIA (2006a).

Uncertainty

There are two primary contributors to the uncertainty of C content coefficients for motor gasoline. The first is the small number of motor gasoline samples and ultimate analyses from Deluchi et al. However, as demonstrated above in Figure A- 3, the amount of variation in C content of gasoline is restricted by the compounds in the fuel to ±4 percent.

The second primary contributor to uncertainty is the assumed heat content. The heat contents are industry standards established many years ago. The heat contents are standard conversion factors used by EIA to convert volumetric energy data to energy units. Because the heat contents of fuels change over time, without necessarily and directly altering their volume, the conversion of known volumetric data to energy units may introduce bias. Thus, a more precise approach to estimating emissions factors would be to calculate C content per unit of volume, rather than per unit of energy. Adopting this approach, however, makes it difficult to compare U.S. C content coefficients with those of other nations.

The changes in density of motor gasoline over the last decade suggest that the heat content of the fuels is also changing. However, that change within any season grade has been less than 1 percent over the decade. Of greater concern is the use of a standardized heat content across grades, which show a variation in density of ±1.5 percent.

Jet Fuel

Jet fuel is a refined petroleum product used in jet aircraft engines. There are two classes of jet fuel used in the United States: "naphtha-based" jet fuels and "kerosene-based" jet fuels. In 1989, 13 percent of U.S. consumption was naphtha-based fuel, with the remainder kerosene-based jet fuel. In 1993, the U.S. Department of Defense began a conversion from naphtha-based JP-4 jet fuel to kerosene-based jet fuel, because of the possibility of increased demand for reformulated motor gasoline limiting refinery production of naphtha-based jet fuel. By 1996, naphtha-based jet fuel represented less than one-half of one percent of all jet fuel consumption. The C content coefficient for jet fuel used in this report represents a consumption-weighted combination of the naphtha-based and kerosene-based coefficients.

Methodology

Step 1. Estimate the carbon content for naphtha-based jet fuels

Because naphtha-based jet fuels are used on a limited basis in the United States, sample data on its characteristics are limited. The density of naphtha-based jet fuel (49 degrees) was estimated as the central point of the acceptable API gravity range published by ASTM. The heat content of the fuel was assumed to be 5.355 MMBtu per barrel based on EIA industry standards. The C fraction was derived from an estimated hydrogen content of 14.1 percent (Martel and Angello 1977), and an estimated content of sulfur and other non-hydrocarbons of 0.1 percent.

Step 2. Estimate the carbon content for kerosene-based jet fuels

The density and C share of kerosene-based jet fuels was based on the average composition of 39 fuel samples taken by Boeing Corporation (the leading U.S. commercial airline manufacturer) in 1989. The EIA's standard heat content of 5.670 MMBtu per barrel was adopted for kerosene-based jet fuel.

Step 3. Weight the overall jet fuel carbon content coefficient for consumption of each type of fuel

The C content for each jet fuel type is multiplied by the share of overall consumption of that fuel type. Individual coefficients are then summed and totaled to yield an overall C content coefficient

Data Sources

Data on the C content of naphtha-based jet fuel was taken from C.R. Martel and L.C. Angello (1977). Data on the density of naphtha-based jet fuel was taken from ASTM (1985). Standard heat contents for kerosene and naphtha-based jet fuels were adopted from EIA (2006a). Data on the C content and density of kerosene-based jet fuel was taken from Hadallar and Momenthy (1990).

Uncertainty

Variability in jet fuel is relatively small with the average C share of kerosene-based jet fuel varying by less than ±1 percent and the density varying by ±1 percent. This is because the ratio of fuel mass to useful energy must be tightly bounded to maximize safety and range. There is more uncertainty associated with the density and C share of naphtha-based jet fuel because sample data were unavailable and default values were used. This uncertainty has only a small impact on the overall uncertainty of the C content coefficient for jet fuels, however, because naphtha-based jet fuel represents a small and declining share of total jet fuel consumption in the United States.

Distillate Fuel

Distillate fuel is a general classification for diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as offhighway engines, such as those in railroad locomotives and agricultural machinery. No. 1, No. 2, and No. 4 fuel oils are also used for space heating and electric power generation.

Methodology

For the purposes of this report, the C content of No. 2 fuel oil is assumed to typify the C content of distillate fuel generally. The C share in No. 2 fuel oil was estimated based on the average of 11 ultimate analyses. This C share was combined with EIA's standard heat content of 5.825 MMBtu per barrel and the density of distillate assumed to be 35.5 degrees API, in accord with its heat content.

Data Sources

Data on C contents and density were derived from four samples from C. T. Hare and R.L. Bradow (1979). Samples were taken from the following sources: Funkenbush, et al. (1979), Mason (1981), and Black and High (1979).

A standard heat content was adopted from EIA (2006a).

Uncertainty

The primary source of uncertainty for the estimated C content of distillate fuel is the selection of No.2 fuel oil as the typical distillate fuel. No.2 fuel oil is generally consumed for home heating. No.1 fuel oil is generally less dense and if it is consumed in large portions for mobile sources, the C content estimated for this report is likely to be too high. The five No.1 fuel oil samples obtained by EIA contained an average of 86.01 percent C compared to the 86.34 percent contained in samples of No.2 fuel oil. A C content coefficient based on No.1 fuel oil would equal 19.72 Tg C/QBtu rather than the 19.95 Tg C/QBtu for No. 2 fuel oil. There is also small uncertainty in the share of C based on the limited sample size of ±1 percent.

Residual Fuel

Residual fuel is a general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. Residual fuel conforms to ASTM Specifications D 396 and D 975 and Federal Specification VV-F-815C. No. 5, a residual fuel oil of medium viscosity, is also known as Navy Special and is defined in Military Specification MIL-F-859E, including Amendment 2 (NATO Symbol F-770). It is used in steam-powered vessels in government service and inshore power plants. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.

In the United States, electric utilities purchase about a third of the residual oil consumed. A somewhat larger share is used for vessel bunkering, and the balance is used in the commercial and industrial sectors. The residual oil (defined as No.6 fuel oil) consumed by electric utilities has an energy content of 6.287 MMBtu per barrel and an average sulfur content of 1 percent (EIA 2001). This implies a density of about 17 degrees API.

Methodology

For this report, residual fuel was defined as No.6 fuel oil. The National Institute of Petroleum and Energy Research, Fuel Oil Survey shows an average density for fuel oil of 11.3 API gravity and anecdotal evidence suggests that marine residual fuel is also very dense, with typical gravity of 10.5 to 11.5 degrees API (EIA 1993). Because the largest share of fuel oil consumption is for marine vessels, a density of 11 degrees API was adopted when developing the C content coefficient for this report. An average share of C in residual fuel of 85.67 percent by mass was used based on ultimate analyses of a dozen samples.

Data Sources

Data on C content were derived from three samples of residual fuel from the Middle East and one sample from Texas. These data were found in Mosby, et al. (1976). Three samples of heavy fuel oils were taken from Longwell (1991); three samples from Ward (1978); two samples from Vorum (1974); and one sample from Rose and Cooper (1977). Density of residual fuel consumed for electric power generation was obtained from EIA (2001). Density of residual fuel consumed in marine vessels was obtained from EIA (1993). A standard heat content was adopted from EIA (2006a).

Uncertainty

The largest source of uncertainty for estimating the C content of residual fuel centers on the estimates of density, which differ from power generation to marine vessel fuels. The difference between the density implied by the energy content of utility fuels and the density observed in the NIPER surveys is probably due to nonsulfur impurities, which reduce the energy content without greatly affecting the density of the product. Impurities of several percent are commonly observed in residual oil. The presence of these impurities also affects the share of the fuel that is C. Overall, the uncertainty associated with the C content of residual fuel is probably ±1 percent.

Liquefied Petroleum Gases (LPG)

EIA identifies four categories of paraffinic hydrocarbons as LPG: ethane, propane, isobutane, and n-butane. Because each of these compounds is a pure paraffinic hydrocarbon, their C shares are easily derived by taking into account the atomic weight of C (12) and the atomic weight of hydrogen (1). Thus, for example, the C share of propane, C_3H_8, is 81.8 percent. The densities and heat content of the compounds are also well known allowing C content coefficients to be calculated directly. Table A-39 summarizes the physical characteristic of LPG.

Table A-39: Physical Characteristics of Liquefied Petroleum Gases

Compound	Chemical Formula	Density (Barrels Per Metric Ton)	Carbon Content (Percent)	Energy Content (MMBtu/Barrel)	Carbon Content Coefficient (Tg C/QBtu)
Ethane	C_2H_6	16.88	80.0	2.916	16.25
Propane	C_3H_8	12.44	81.8	3.824	17.20
Isobutane	C_4H_{10}	11.20	82.8	4.162	17.75
n-butane	C_4H_{10}	10.79	82.8	4.328	17.72

Source: Guthrie (1960).

Methodology

Step 1. Assign carbon content coefficients to each pure paraffinic compound

Based on their known physical characteristics, a C content coefficient is assigned to each compound contained in the U.S. energy statistics category, Liquefied Petroleum Gases.

Step 2. Weight individual LPG coefficients for share of fuel use consumption

A C content coefficient for LPG used as fuel is developed based on the consumption mix of the individual compound reported in U.S. energy statistics.

Step 3. Weight individual LPG coefficients for share of non-fuel use consumption

The mix of LPG consumed for non-fuel use differs significantly from the mix of LPG that is combusted. While the majority of LPG consumed for fuel use is propane, ethane is the largest component of LPG used for non-fuel applications. A C content coefficient for LPG used for non-fuel applications is developed based on the consumption mix of the individual compound reported in U.S. energy statistics.

Step 4. Weight the carbon content coefficients for fuel use and non-fuel use by their respective shares of consumption

The changing shares of LPG fuel use and non-fuel use consumption appear below in Table A-40.

Data Sources

Data on C share, density, and heat content of LPG was obtained from Guthrie (1960). LPG consumption was based on data obtained from API (1990-2005) and EIA (2006b). Non-fuel use of LPG was obtained from API (1990 through 2005).

Uncertainty

Because LPG consists of pure paraffinic compounds whose density, heat content and C share are physical constants, there is limited uncertainty associated with the C content coefficient for this petroleum product. Any uncertainty is associated with the collection of consumption data and non-fuel data in U.S. energy statistics. This uncertainty is probably less than ±3 percent.

Table A-40: Consumption and Carbon Content Coefficients of Liquefied Petroleum Gases, 1990-2005

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Energy Consumption (QBtu)																
Fuel Use	**0.86**	**0.86**	**0.94**	**0.94**	**0.96**	**0.93**	**1.02**	**1.03**	**0.84**	**1.09**	**1.29**	**1.15**	**1.24**	**1.21**	**1.25**	**1.20**
Ethane	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.05	0.00	0.00	0.08	0.05	0.05	0.05	0.05	0.04
Propane	0.75	0.79	0.84	0.86	0.86	0.86	0.95	0.92	0.80	0.97	1.08	1.01	1.10	1.07	1.13	1.08
Butane	0.08	0.05	0.07	0.06	0.07	0.05	0.04	0.05	0.04	0.11	0.14	0.10	0.09	0.09	0.07	0.07
Non-Fuel Use	**1.20**	**1.38**	**1.39**	**1.35**	**1.55**	**1.59**	**1.65**	**1.67**	**1.74**	**1.82**	**1.67**	**1.55**	**1.62**	**1.55**	**1.58**	**1.49**
Ethane	0.55	0.62	0.62	0.65	0.65	0.68	0.74	0.71	0.73	0.82	0.80	0.73	0.77	0.70	0.74	0.70
Propane	0.53	0.59	0.61	0.55	0.65	0.67	0.65	0.71	0.77	0.77	0.66	0.59	0.65	0.63	0.66	0.64
Butane	0.13	0.17	0.16	0.15	0.25	0.24	0.26	0.25	0.24	0.22	0.21	0.23	0.21	0.22	0.17	0.15
Carbon Content (Tg C/QBtu)																
Fuel Use	17.21	17.21	17.21	17.22	17.22	17.20	17.20	17.18	17.23	17.25	17.20	17.21	17.20	17.21	17.20	17.20
Non-Fuel Use	16.83	16.84	16.84	16.80	16.88	16.87	16.86	16.88	16.88	16.84	16.81	16.83	16.82	16.84	16.81	16.81

Sources: Fuel use of LPG based on data from EIA (2006b) and API (1990 through 2005). Non-fuel use of LPG from API (1990 through 2005). C contents from EIA (2006a).

Aviation Gasoline

Aviation gasoline is used in piston-powered airplane engines. It is a complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D910 and Military Specification MIL-G-5572. Aviation gas is a relatively minor contributor to greenhouse gas emissions compared to other petroleum products, representing approximately 0.1 percent of all consumption.

The ASTM standards for boiling and freezing points in aviation gasoline effectively limit the aromatics content to a maximum of 25 percent (ASTM D910). Because weight is critical in the operation of an airplane, aviation gas must have as many Btu per pound (implying a lower density) as possible, given other requirements of piston engines such as high anti-knock quality.

Methodology

A C content coefficient for aviation gasoline was calculated on the basis of the EIA standard heat content of 5.048 MMBtu per barrel. This implies a density of approximately 69 degrees API gravity or 5.884 pounds per gallon. To estimate the share of C in the fuel, it was assumed that aviation gasoline is 87.5 percent isooctane, 9.0 percent toluene, and 3.5 percent xylene. The maximum allowable sulfur content in aviation gasoline is 0.05 percent, and the maximum allowable lead content is 0.1 percent. These amounts were judged negligible and excluded for the purposes of this analysis. This yielded a C share of 85 percent and a C content coefficient of 18.87 Tg C/QBtu.

Data Sources

Data sources include ASTM (1985). A standard heat content for aviation gas was adopted from EIA (2006a).

Uncertainty

The uncertainty associated with the C content coefficient for aviation gasoline is larger than that for other liquid petroleum products examined because no ultimate analyses of samples are available. Given the requirements for safe operation of piston-powered aircraft the composition of aviation gas is well bounded and the uncertainty of the C content coefficient is likely to be ±5 percent.

Still Gas

Still gas, or refinery gas is composed of light hydrocarbon gases that are released as petroleum is processed in a refinery. The composition of still gas is highly variable, depending primarily on the nature of the refining process and secondarily on the composition of the product being processed. Petroleum refineries produce still gas from many different processes. Still gas can be used as a fuel or feedstock within the refinery, sold as a petrochemical feedstock, or purified and sold as pipeline-quality natural gas. In general, still gas tends to include large amounts of free hydrogen and methane, as well as smaller amounts of heavier hydrocarbons. Because different refinery operations result in different gaseous byproducts, it is difficult to determine what represents typical still gas.

Methodology

The EIA obtained data on four samples of still gas. Table A-41 below shows the composition of those samples.

Table A-41: Composition, Energy Content, and Carbon Content Coefficient for Four Samples of Still Gas

Sample	Hydrogen (%)	Methane (%)	Ethane (%)	Propane (%)	Btu Per Cubic Foot	Carbon Content (Tg C/QBtu)
One	12.7	28.1	17.1	11.9	1,388	17.51
Two	34.7	20.5	20.5	6.7	1,143	14.33
Three	72.0	12.8	10.3	3.8	672	10.23
Four	17.0	31.0	16.2	2.4	1,100	15.99

Because gas streams with a large free hydrogen content are likely to be used as refinery or chemical feedstocks, EIA selected the C content coefficient from the sample with the lowest hydrogen content as the representative value for still gas.

Data Sources

Data sources include one still gas sample from American Gas Association (1974) and three still gas samples from Guerra, et al. (1979).

Uncertainty

Because the composition of still gas is highly heterogeneous, the C content coefficient for this product is highly uncertain, with an accuracy of ±33 percent. The C content coefficient used for this report is probably at the high end of the plausible range.

Asphalt

Asphalt is used to pave roads. Because most of its C is retained in those roads, it is a small source of emissions. It is derived from a class of hydrocarbons called "asphaltenes," abundant in some crude oils but not in others. Asphaltenes have oxygen and nitrogen atoms bound into their molecular structure, so that they tend to have lower C contents than other hydrocarbons.

Methodology

Ultimate analyses of twelve samples of asphalts showed an average C content of 83.5 percent. The EIA standard Btu content for asphalt of 6.636 MMBtu per barrel was assumed. The ASTM petroleum measurement tables show a density of 5.6 degrees API or 8.605 pounds per gallon for asphalt. Together, these variables generate C content coefficient of 20.62 Tg C/QBtu.

Data Sources

A standard heat content for asphalt was adopted from EIA (2006a). The density of asphalt was determined by the ASTM (1985).

Uncertainty

The share of C in asphalt ranges from 79 to 88 percent by weight. Also present in the mixture are hydrogen and sulfur, with shares by weight ranging from seven to 13 percent for hydrogen, and from trace levels to eight percent for sulfur. Because C share and total heat content in asphalts do vary systematically, the overall C content coefficient is likely to be accurate to ±5 percent.

Lubricants

Lubricants are substances used to reduce friction between bearing surfaces, or incorporated into processing materials used in the manufacture of other products, or used as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Lubricants include all grades of lubricating oils, from spindle oil to cylinder oil to those used in greases. Lubricant consumption is dominated by motor oil for automobiles, but there is a large range of product compositions and end uses within this category.

Methodology

The ASTM Petroleum Measurement tables give the density of lubricants at 25.6 degrees API. Ultimate analysis of a single sample of motor oil yielded a C content of 85.8 percent. A standard heat content of 6.065 MMBtu per barrel was adopted from EIA. These factors produce a C content coefficient of 20.24 Tg C/QBtu.

Data Sources

A standard heat content was adopted from the EIA (2006a). The density of asphalt was determined by ASTM (1985).

Uncertainty

Uncertainty in the estimated C content coefficient for lubricants is driven by the large range of product compositions and end uses in this category combined with an inability to establish the shares of the various products captured under this category in U.S. energy statistics. Because lubricants may be produced from either the distillate or residual fractions during refineries, the possible C content coefficients range from just under 20.0 Tg C/QBtu to about 21.5 Tg C/QBtu or an uncertainty band from –1 percent to + 6 percent of the estimated value.

Petrochemical Feedstocks

U.S. energy statistics distinguish between two different kinds of petrochemical feedstocks: those with a boiling temperature below 400 degrees Fahrenheit, generally called "naphtha," and those with a boiling temperature 400 degrees Fahrenheit and above.

Methodology

The method for estimating the C content of petrochemical feedstocks includes three steps.

Step 1. Estimate the carbon content coefficient for naphtha

Because reformed naphtha is used to make motor gasoline (hydrogen is released to raise aromatics content and octane rating), "straight-run" naphtha is assumed to be used as a petrochemical feedstock. Ultimate analyses of five samples of naphtha were examined and showed an average C share of 84.11 percent and an average density of 67.1 degrees API gravity. The standard EIA heat content of 5.248 MMBtu per barrel is used to estimate a C content coefficient of 18.14 Tg C/QBtu.

Step 2. Estimate the carbon content coefficient for petrochemical feedstocks with a boiling temperature 400 degrees Fahrenheit and above

The boiling temperature of this product places it into the "middle distillate" fraction in the refining process, and EIA estimates that these petrochemical feedstocks have the same heat content as distillate fuel. Thus, the C content coefficient of 19.95 Tg C/QBtu used for distillate fuel is also adopted for this portion of petrochemical feedstocks.

Step 3. Weight the carbon content coefficients for the two classes of petrochemical feedstock by consumption

The weighted average of the two C content coefficients for petroleum feedstocks equals 19.37 Tg C/QBtu.

Data Sources

Data on the C content and density of naphtha was taken from Unzelman (1992). A standard heat content for petrochemical feedstock was adopted from EIA (2006a).

Uncertainty

Petrochemical feedstocks are not so much distinguished on the basis of chemical composition as on the identity of the purchaser, who may be presumed to be a chemical company or a petrochemical unit co-located on the refinery grounds. This produces a considerable degree of uncertainty about the exact composition of petrochemical feedstocks. Since the C content coefficient for petrochemical feedstocks is a weighted average of the coefficients for naphtha and some class of middle distillates, the accurate coefficient is likely bounded by the two individual coefficients, suggesting an uncertainty of ±6 percent.

Kerosene

A light petroleum distillate that is used in space heaters, cook stoves, and water heaters and is suitable for use as a light source when burned in wick-fed lamps, kerosene is drawn from the same petroleum fraction as jet fuel. Kerosene is generally comparable to No.1 fuel oil.

Methodology

The average density of 41.4 degrees API and average C share of 86.01 percent found in five ultimate analyses of No. 1 fuel oil samples were applied to a standard heat content of 5.670 MMBtu per barrel to yield a C content coefficient of 19.72 Tg C/QBtu.

Data Sources

A standard heat content was adopted from EIA (2006a).

Uncertainty

Uncertainty in the estimated C content for kerosene is driven by the selection of No. 1 fuel oil as a proxy for kerosene. If kerosene is more like kerosene-based jet fuel, the true C content coefficient is likely to be some 2 percent lower. If kerosene is more aptly compared to No. 2 fuel oil, then the true C content coefficient is likely to be about 1 percent higher.

Petroleum Coke

Petroleum coke is the solid residue by-product of the extensive processing of crude oil. It is a coal-like solid, usually with a C content greater than 90 percent, that is used as a boiler fuel and industrial raw material.

Methodology

Ultimate analyses of two samples of petroleum coke showed an average C share of 92.3 percent. The ASTM standard density of 9.543 pounds per gallon was adopted and the EIA standard energy content of 6.024 MMBtu per barrel assumed. Together, these factors produced an estimated C content coefficient of 27.85 Tg C/QBtu.

Data Sources

C content was derived from two samples from Martin, S.W. (1960). The density of petroleum coke was taken from the ASTM (1985). A standard heat content for petroleum coke was adopted from EIA (2006a).

Uncertainty

The uncertainty associated with the estimated C content coefficient of petroleum coke can be traced to two factors: the use of only two samples to establish C contents and a standard heat content which may be too low. Together, these uncertainties are likely to bias the C content coefficient upwards by as much as 6 percent.

Special Naphtha

Special naphtha is defined as a light petroleum product to be used for solvent applications, including commercial hexane and four classes of solvent: stoddard solvent, used in dry cleaning; high flash point solvent, used as an industrial paint because of its slow evaporative characteristics; odorless solvent, most often used for residential paints; and high solvency mineral spirits, used for architectural finishes. These products differ in both density and C percentage, requiring the development of multiple coefficients.

Methodology

The method for estimating the C content coefficient of special naphtha includes three steps.

Step 1. Estimate the carbon content coefficient for hexane

Hexane is a pure paraffin containing 6 C atoms and 14 hydrogen atoms; thus, it is 83.7 percent C. Its density is 76.6 degrees API or 5.649 pounds per gallon and its derived C content coefficient is 17.17 Tg C/QBtu.

Step 2. Estimate the carbon contents of non-hexane special naphthas

The hydrocarbon compounds in special naphthas are assumed to be either paraffinic or aromatic (see discussion above). The portion of aromatics in odorless solvents is estimated at less than 1 percent, Stoddard and high flash point solvents contain 15 percent aromatics and high solvency mineral spirits contain 30 percent aromatics (Boldt and Hall 1977). These assumptions, when combined with the relevant densities, yield the C content factors contained in Table A-42, below.

Table A-42: Characteristics of Non-hexane Special Naphthas

Special Naphtha	Aromatic Content (Percent)	Density (Degrees API)	Carbon Content (Percent)	Carbon Content (Tg C/QBtu)
Odorless Solvent	1	55.0	84.51	19.41
Stoddard Solvent	15	47.9	84.44	20.11
High Flash Point	15	47.6	84.70	20.17
Mineral Spirits	30	43.6	85.83	20.99

Step 3. Develop weighted carbon content coefficient based on consumption of each special naphtha

EIA reports only a single consumption figure for special naphtha. The C contents of the five special naphthas are weighted according to the following formula: approximately 10 percent of all special naphtha consumed is hexane; the remaining 90 percent is assumed to be distributed evenly among the four other solvents. The resulting emissions coefficient for special naphthas is 19.86 Tg C/QBtu.

Data Sources

A standard heat content for special naphtha was adopted from EIA (2006a). Density and aromatic contents were adopted from Boldt and Hall (1977).

Uncertainty

The principal uncertainty associated with the estimated C content coefficient for special naphtha is the allocation of overall consumption across individual solvents. The overall uncertainty is bounded on the low end by the C content of hexane and on the upper end by the C content of high solvency mineral spirits. This implies an uncertainty band of –15 percent to +6 percent.

Petroleum Waxes

The ASTM standards define petroleum wax as a product separated from petroleum that is solid or semi-solid at 77 degrees Fahrenheit (25 degrees Celsius). The two classes of petroleum wax are paraffin waxes and microcrystalline waxes. They differ in the number of C atoms and the type of hydrocarbon compounds. Microcrystalline waxes have longer C chains and more variation in their chemical bonds than paraffin waxes.

Methodology

The method for estimating the C content coefficient for petroleum waxes includes three steps.

Step 1. Estimate the carbon content of paraffin waxes

For the purposes of this analysis, paraffin waxes are assumed to be composed of 100 percent paraffinic compounds with a chain of 25 C atoms. The resulting C share for paraffinic wax is 85.23 percent and the density is estimated at 45 degrees API or 6.684 pounds per gallon.

Step 2. Estimate the carbon content of microcrystalline waxes

Microcrystalline waxes are assumed to consist of 50 percent paraffinic and 50 percent cycloparaffinic compounds with a chain of 40 C atoms, yielding a C share of 85.56 percent. The density of microcrystalline waxes is estimated at 36.7 degrees API, based on a sample of 10 microcrystalline waxes found in the *Petroleum Products Handbook*.

Step 3. Develop a carbon content coefficient for petroleum waxes by weighting the density and carbon content of paraffinic and microcrystalline waxes

A weighted average density and C content was calculated for petroleum waxes, assuming that wax consumption is 80 percent paraffin wax and 20 percent microcrystalline wax. The weighted average C content is 85.29 percent, and the weighted average density is 6.75 pounds per gallon. EIA's standard heat content for waxes is 5.537 MMBtu per barrel. These inputs yield a C content coefficient for petroleum waxes of 19.81 Tg C/QBtu.

Data Sources

Density of paraffin wax was taken from ASTM (1985). Density of microcrystalline waxes was derived from 10 samples found in Guthrie (1960). A standard heat content for petroleum waxes was adopted from EIA (2006a).

Uncertainty

Although there is considerable qualitative uncertainty associated with the allocation of petroleum waxes and microcrystalline waxes, the quantitative variation in the C contents for all waxes is limited to ± 1 percent because of the nearly uniform relationship between C and other elements in petroleum waxes broadly defined.

Crude Oil, Unfinished Oils, and Miscellaneous

U.S. energy statistics include several categories of petroleum products designed to ensure that reported refinery accounts "balance" and cover any "loopholes" in the taxonomy of petroleum products. These categories include crude oil, unfinished oils, and miscellaneous products. Crude oil is rarely consumed directly, miscellaneous products account for less than one percent of oil consumption, and unfinished oils are a balancing item that may show negative consumption. For C accounting purposes, it was assumed that all these products have the same C content as crude oil.

Methodology

EIA reports on the average density and sulfur content of U.S. crude oil purchased by refineries. To develop a method of estimating C content based on this information, ultimate analyses of 182 crude oil samples were collected. Within the sample set, C content ranged from 82 to 88 percent C, but almost all samples fell between 84 percent and 86 percent C. The density and sulfur content of the crude oil data were regressed on the C content, producing the following equation:

$$\text{Percent C} = 76.99 + (10.19 \times \text{Specific Gravity}) + (-0.76 \times \text{Sulfur Content})$$

Absent the term representing sulfur content, the equation had an R-squared of only 0.35.[1] When C content was adjusted to exclude sulfur, the R-squared value rose to 0.65. While sulfur is the most important nonhydrocarbon impurity, nitrogen and oxygen can also be significant, but they do not seem to be correlated with either density or sulfur content. Restating these results, density accounts for about 35 percent of the variation in C content, impurities account for about 30 percent of the variation, and the remaining 35 percent is accounted for by other factors, including (presumably) the degree to which aromatics and polynuclear aromatics are present in the crude oil. Applying this equation to the 2001 crude oil quality data (30.49 degrees API and 1.42 percent sulfur) produces an estimated C content of 85.81 percent. Applying the density and C content to the EIA standard energy content for crude oil of 5.800 MMBtu per barrel produced an emissions coefficient of 20.33 Tg C/QBtu.

Data Sources

C content was derived from 150 crude oil samples from U.S. National Research Council (1927). A standard heat content for crude oil was adopted from EIA (2006a).

Uncertainty

The uncertainty of the estimated C content for crude oil centers on the 35 percent of variation that cannot be explained by density and sulfur content. This variation is likely to alter the C content coefficient by ±3 percent. Since unfinished oils and miscellaneous products are impossible to define, the uncertainty of applying a crude oil C content is likely to be bounded by the range of petroleum products described in this chapter at ±10 percent.

Chronology and Explanation of Changes in Individual Carbon Content Coefficients of Fossil Fuels

Coal

The estimates of C content coefficients for coal were updated and revised in 2005. The methodology employed for these estimates was unchanged from previous years; however, the underlying coal data sample set was updated. Previously a set of 5,426 coal samples from the EIA Coal Analysis File was used to develop C content estimates. The results from that sample set appear below in Table A-43. The EIA Coal Analysis File was originally developed by the U.S. Bureau of Mines and contained over 60,000 coal samples obtained through numerous coal

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[1] R-squared represents the percentage of variation in the dependent variable (in this case carbon content) explained by variation in the independent variables.

seams throughout the United States. Many of the samples were collected starting in the 1940s and 1950s through the 1980s and analyzed in U.S. government laboratories. The updated sample set included 6,588 coal samples collected by the U.S. Geological Survey between 1973 and 1989.

Petroleum Products

Jet Fuel

Between 1994 and 1995, the C content coefficient for kerosene-based jet fuel was revised downward from 19.71 Tg C/QBtu to 19.33 Tg C/QBtu. This downward revision was the result of a shift in the sample set used from one collected between 1959 and 1972 and reported on by Martel and Angello in 1977 to one collected by Boeing in 1989 and published by Hadaller and Momenthy in 1990. The downward revision was a result of a decrease in density, as well as slightly lower C shares than in the earlier samples. However, the assumed heat content is unchanged because it is based on an EIA standard and probably yields a downward bias in the revised C content coefficient.

Liquefied Petroleum Gases (LPG)

The C content coefficient of LPG is updated annually to reflect changes in the consumption mix of the underlying compounds: ethane; propane; isobutane; and normal butane. In 1994, EIA included pentanes plus—assumed to have the characteristics of hexane—in the mix of compounds broadly described as LPG. In 1995, EIA removed pentanes plus from this fuel category. Because pentanes plus is relatively rich in C per unit of energy, its removal from the consumption mix lowered the C content coefficient for LPG from 17.26 Tg C/QBtu to 16.99 Tg C/QBtu. In 1998, EIA began separating LPG consumption into two categories: energy use and non-fuel use and providing individual coefficients for each. Because LPG for fuel use typically contains higher proportions of propane than LPG for non-fuel use, the C content coefficient for fuel use is about 2 percent higher than the coefficient for non-fuel use.

Motor Gasoline

The C content coefficient for motor gasoline varies annually based on the density of and proportion of additives in a representative sample of motor gasoline examined each year. However, in 1997 EIA began incorporating the effects of the introduction of reformulated gasoline into its estimate of C content coefficients for motor gasoline. This change resulted in a downward step function in C content coefficients for gasoline of approximately 0.3 percent beginning in 1995.

Table A-43: Carbon Content Coefficients for Coal by Consuming Sector and Coal Rank, 1990-2005 [Tg C/QBtu)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Consuming Sector																
Electric Power	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76	25.76
Industrial Coking	25.51	25.51	25.51	25.51	25.52	25.53	25.55	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56	25.56
Other Industrial	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
Residential/Commercial	25.92	26.00	26.13	25.97	25.95	26.00	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Coal Rank																
Anthracite	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26	28.26
Bituminous	25.43	25.45	25.44	25.45	25.46	25.47	25.47	25.48	25.47	25.48	25.49	25.49	25.49	25.49	25.49	25.49
Sub-bituminous	26.50	26.49	26.49	26.48	26.49	26.49	26.49	26.49	26.49	26.49	26.48	26.48	26.48	26.48	26.48	26.48
Lignite	26.19	26.21	26.22	26.21	26.24	26.22	26.17	26.20	26.23	26.26	26.30	26.30	26.30	26.30	26.30	26.30

p (Preliminary)

Sources: C content coefficients by consuming sector from EIA (2006a). C content coefficients by coal rank from USGS (1998) and SAIC (2005).

References

American Gas Association (1974) *Gas Engineer's Handbook,* New York, NY, Industrial Press, pp. 3/71, 3.87.

API (1990 through 2005) *Sales of Natural Gas Liquids and Liquefied Refinery Gases*, American Petroleum Institute.

API (1988) *Alcohols and Ethers: A Technical Assessment of Their Applications as Fuels and Fuel Components*, American Petroleum Institute, API 4261.

Applied Systems Corporation (1976) *Compilation of Oil Shale Test Results,* submitted to the Office of Naval Research, April 1976, p. 3-2.

ASTM (1985) *ASTM and Other Specifications for Petroleum Products and Lubricants,* American Society for Testing and Materials. Philadelphia, PA.

Black, F. and L. High (1979) "Methodology for Determining Particulate and Gaseous Diesel Emissions," in, *The Measurement and Control of Diesel Particulate Emissions,* Society of Automotive Engineers, p. 128.

Boldt, K. and B.R. Hall (1977) *Significance of Tests for Petroleum Products*, Philadelphia, PA, American Society for Testing and Materials, p. 30.

DeLuchi (1993) *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,* Volume 2, ANL/ESD/TM-22, Vol. 2. Chicago, IL, Argonne National Laboratory. Appendix C, pp. C-1 to C-8.

DOC (1929) *Thermal Properties of Petroleum Products*, U.S. Department of Commerce, National Bureau of Standards. Washington, DC. pp.16-21.

EIA (1993) *Btu Tax on Finished Petroleum Products,* Energy Information Administration, Petroleum Supply Division (unpublished manuscript, April 1993).

EIA (1994) *Emissions of Greenhouse Gases in the United States 1987-1992*, Energy Information Administration, U.S. Department of Energy. Washington, DC. November, 1994. DOE/EIA 0573.

EIA (2001) *Cost and Quality of Fuels for Electric Utility Plants 2000*, Energy Information Administration. Washington, DC. August 2001. Available online at <http://www.eia.doe.gov/cneaf/electricity/cq/cq_sum.html>.

EIA (2002) *Coal Industry Annual,* U.S. Department of Energy, Energy Information Administration. Washington, DC.

EIA (2003) *State Energy Data 2000: Consumption*, Energy Information Administration, U.S. Department of Energy, Washington, DC. August 2003. Available online at <http://www.eia.doe.gov/emeu/states/_use_multistate.html>.

EIA (2006a) *Monthly Energy Review, December 2006 and Unpublished Supplemental Tables on Petroleum Product detail: Table A4*. Energy Information Administration, U.S. Department of Energy, Washington, DC, DOE/EIA-0035(2006/12).

EIA (2006b) *Petroleum Supply Annual*, Energy Information Administration, U.S. Department of Energy, Washington, DC. Available online at <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum_supply_annual/psa_volume1/psa_volume1.html>.

Funkenbush, E.F., D.G. Leddy, and J.H. Johnson (1979) "The Organization of the Soluble Organic Fraction of Diesel Particulate Matter," in Society of Automotive Engineers, *The Measurement and Control of Diesel Particulate Emissions*, p. 128.

Gas Technology Institute (1992) Database as documented in W.E. Liss, W.H. Thrasher, G.F. Steinmetz, P. Chowdiah, and A. Atari, *Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States.* GRI-92/0123. March 1992.

Guerra, C.R., K. Kelton, and D.C. Nielsen (1979) "Natural Gas Supplementation with Refinery Gases and Hydrogen," in Institute of Gas Technology, *New Fuels and Advances in Combustion Technologies*. Chicago, IL, June 1979.

Guthrie, V.B. (ed.) (1960) *Characteristics of Compounds*, Petroleum Products Handbook, p.3-3. New York, NY, McGraw-Hill.

Hadaller, O.J. and A.M. Momenthy (1990) *The Characteristics of Future Fuels,* Part 1, "Conventional Heat Fuels". Seattle, WA, Boeing Corp. September 1990. pp. 46-50.

Hare, C.T. and R.L. Bradow (1979) "Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and the Effects of Fuel Composition," in Society of Automotive Engineers, *The Measurement and Control of Diesel Particulate Emissions*, p. 128.

Hunt, J.M. (1979) Petroleum Geochemistry and Geology. San Francisco, CA. W.H. Freeman and Company. pp. 31-37.

Longwell, J.P. (1991) "Interface Between Fuels and Combustion," in *Fossil Fuel Combustion: A Sourcebook,* New York, NY, John Wiley & Sons.

Martel, C.R., and L.C. Angello (1977) "Hydrogen Content as a Measure of the Combustion Performance of Hydrocarbon Fuels," in *Current Research in Petroleum Fuels,* Volume I. New York, NY, MSS Information Company, p. 116.

Martin, S.W. (1960) "Petroleum Coke," in Virgil Guthrie (ed.), *Petroleum Processing Handbook,* New York, NY, McGraw-Hill, pp. 14-15.

Mason, R.L. (1981) "Developing Prediction Equations for Fuels and Lubricants," SAE Paper 811218, p.34. October 1981.

Mosby, F., G.B. Hoekstra, T.A. Kleinhenz, and J.M. Sokra (1976) "Pilot Plant Proves Resid Process," in *Chemistry of Petroleum Processing and Extraction*, MSS Information Corporation, p.227.

National Institute for Petroleum and Energy Research (1990 through 2005) *Motor Gasolines, Summer* and *Motor Gasolines, Winter*.

Ringen, S., J. Lanum, and F.P. Miknis (1979) "Calculating Heating Values from the Elemental Composition of Fossil Fuels," *Fuel,* Vol. 58, January 1979, p.69.

Rose, J.W. and J.R. Cooper (1977) *Technical Data on Fuel,* The British National Committee, World Energy Conference, London, England.

SAIC (2005) Analysis prepared by Science Applications International Corporation for EPA, Office of Air and Radiation, Market Policies Branch.

U.S. National Research Council (1927) *International Critical Tables of Numerical Data, Physics, Chemistry, and Technology,* New York, NY, McGraw-Hill.

Unzelman, G.H. (1992) "A Sticky Point for Refiners: FCC Gasoline and the Complex Model," *Fuel Reformulation*, July/August 1992, p. 29.

USGS (1998) *CoalQual Database Version 2.0*, U.S. Geological Survey.

Vorum, D.A. (1974) "Fuel and Synthesis Gases from Gaseous and Liquid Hydrocarbons," in American Gas Association, *Gas Engineer's Handbook,* New York, NY, Industrial Press, p. 3/71.

Ward, C.C (1978) "Petroleum and Other Liquid Fuels," in *Marks' Standard Handbook for Mechanical Engineers,* New York, NY, McGraw-Hill, pp. 7-14.

2.3. Methodology for Estimating Carbon Emitted from Non-Energy Uses of Fossil Fuels

C storage associated with the non-energy use of fossil fuels was calculated by multiplying each fuel's potential emissions (i.e., each fuel's total C content) by a fuel-specific storage factor, as listed in Table A-44. The remaining C—i.e., that which is not stored—is emitted. This subannex explains the methods and data sources employed in developing the storage factors for petrochemical feedstocks (industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha), asphalt and road oil, lubricants, waxes, and miscellaneous products. The storage factors[11] for the remaining non-energy fuel uses are either based on values recommended for use by IPCC (1997), or when these were not available, assumptions based on the potential fate of C in the respective NEU products.

Table A-44: Fuel Types and Percent of C Stored for Non-Energy Uses

Sector/Fuel Type	Storage Factor (%)
Industry	-
Industrial Coking Coal[a]	0.10
Industrial Other Coal [b]	0.61
Natural Gas to Chemical Plants [b]	0.61
Asphalt & Road Oil	1.00
LPG [b]	0.61
Lubricants	0.09
Pentanes Plus [b]	0.61
Naphtha (<401 deg. F) [b]	0.61
Other Oil (>401 deg. F) [b]	0.61
Still Gas [b]	0.61
Petroleum Coke[c]	0.50
Special Naphtha [b]	0.61
Distillate Fuel Oil	0.50
Waxes	0.58
Miscellaneous Products	0.00
Transportation	
Lubricants	0.09
U.S. Territories	
Lubricants	0.09
Other Petroleum (Misc. Prod.)	0.10

- Not applicable

[a] Includes processes for which specific coking coal consumption and emission factor data are not available. Consumption of coking coal for production of iron and steel is covered in the Industrial Processes chapter.

[b] The storage factor listed is the value for 2005. As described in this annex, the factor varies over time.

[c] Includes processes for which specific petroleum coke consumption and emission factor data are not available (e.g., C fibers and textiles, refractory, electric motor parts, brake parts, batteries). Consumption of petroleum coke for production of primary aluminum anodes, electric arc furnace anodes, titanium dioxide, ammonia, urea, and ferroalloys is covered in the Industrial Processes chapter.

The following sections describe the non-energy uses in greater detail, outlining the methods employed and data used in estimating each storage factor. Several of the fuel types tracked by EIA are used in organic chemical synthesis and in other manufacturing processes, and are referred to collectively as "petrochemical feedstocks." Because the methods and data used to analyze them overlap, they are handled as a group and are discussed first. Discussions of the storage factors for asphalt and road oil, lubricants, waxes, and miscellaneous products follow.

[11] Throughout this section, references to "storage factors" represent the proportion of carbon stored.

Petrochemical Feedstocks

Petrochemical feedstocks—industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha—are used in the manufacture of a wide variety of man-made chemicals and products. Plastics, rubber, synthetic fibers, solvents, paints, fertilizers, pharmaceuticals, and food additives are just a few of the derivatives of these fuel types. Chemically speaking, these fuels are diverse, ranging from simple natural gas (i.e., predominantly CH_4) to heavier, more complex naphthas and other oils.[12]

After adjustments for (1) use in industrial processes and (2) net exports, these eight fuel categories constituted approximately 210.73 Tg CO_2 Eq., or 53 percent, of the 385.5 Tg CO_2 Eq. of non-energy fuel consumption in 2005. For 2005 the storage factor for the eight fuel categories was 61 percent. In other words, of the net consumption, 61 percent was destined for long-term storage in products—including products subsequently combusted for waste disposal—while the remaining 39 percent was emitted to the atmosphere directly as CO_2 (e.g., through combustion of industrial byproducts) or indirectly as CO_2 precursors (e.g., through evaporative product use). The indirect emissions include a variety of organic gases such as volatile organic compounds (VOCs) and carbon monoxide (CO), which eventually oxidize into CO_2 in the atmosphere. The derivation of the storage factor is described in the following sections.

Methodology and Data Sources

The petrochemical feedstocks storage factor is equal to the ratio of C stored in the final products to total C content for the non-energy fossil fuel feedstocks used in industrial processes, after adjusting for net exports of feedstocks. One aggregate storage factor was calculated to represent all eight fuel feedstock types. The feedstocks were grouped because of the overlap of their derivative products. Due to the many reaction pathways involved in producing petrochemical products (or wastes), it becomes extraordinarily complex to link individual products (or wastes) to their parent fuel feedstocks.

Import and export data for feedstocks were obtained from the Energy Information Administration (EIA) for the major categories of petrochemical feedstocks. EIA's *Petroleum Supply Annual* (EIA 2006) publication tracks imports and exports of petrochemical feedstocks, including butanes, butylenes, ethane, ethylene, propane, propylene, LPG, and naphthas (i.e., most of the large volume primary chemicals produced by petroleum refineries). These imports and exports are already factored into the U.S. fuel consumption statistics. However, EIA does not track imports and exports of chemical intermediates and products produced by the chemical industry (e.g., xylenes, vinyl chloride), which are derived from the primary chemicals produced by the refineries. These products represent very large flows of C derived from fossil fuels (i.e., fossil C), so estimates of net flows not already considered in EIA's dataset were developed for the entire time series from 1990 to 2005.

The approach to estimate imports and exports involves three steps, listed here and then described in more detail below:

Step 1. Identify commodities derived from petrochemical feedstocks, and calculate net import/export for each.

Step 2. Estimate the C content for each commodity.

Step 3. Sum the net C imports/exports across all commodities.

Step 1 relies heavily on information provided by the National Petrochemical and Refiners Association (NPRA) and U.S. Bureau of the Census (BoC) trade statistics published by the U.S. International Trade Commission (USITC). NPRA provided a spreadsheet of the ten-digit BoC Harmonized Tariff Schedule (HTS) Commodity Codes used to compile import-export data for periodic reports issued to NPRA's membership on trade issues. Additional feedstock commodities were identified by HTS code in the BoC data system and included in the net import/export analysis.

One of the difficulties in analyzing trade data is that a large portion of the outputs from the refining industry are fuels and fuel components, and it was difficult to segregate these from the outputs used for non-energy

[12] Naphthas are compounds distilled from petroleum containing 4 to 12 carbon atoms per molecule and having a boiling point less than 401° F. "Other oils" are distillates containing 12 to 25 carbon atoms per molecule and having a boiling point greater than 401° F.

uses. The NPRA-supplied codes identify fuels and fuel components, thus providing a sound basis for isolating net imports/exports of petrochemical feedstocks. Although MTBE and related ether imports are included in the published NPRA data, these commodities are not included in the total net imports/exports calculated here, because it is assumed that they are fuel additives and do not contribute to domestic petrochemical feedstocks. Net exports of MTBE and related ethers are also not included in the totals, as these commodities are considered to be refinery products that are already accounted for in the EIA data. Imports and exports of commodities for which production and consumption data are provided by EIA (e.g., butane, ethylene, and liquefied petroleum gases) are also not included in the totals, to avoid double-counting.

Another difficulty is that one must be careful to assure that there is not double-counting of imports and exports in the data set. Other parts of the mass balance (described later) provide information on C flows, in some cases based on production data and in other cases based on consumption data. Production data relates only to production within the country; consumption data incorporates information on imports and exports as well as production. Because many commodities are emissive in their use, but not necessarily their production, consumption data is appropriately used in calculations for emissive fates. For purposes of developing an overall mass balance on U.S. non-energy uses of C, for those materials that are non-emissive (e.g., plastics), production data is most applicable. And for purposes of adjusting the mass balance to incorporate C flows associated with imports and exports, it was necessary to carefully review whether the mass balance already incorporated cross-boundary flows (through the use of consumption data) or not, and to adjust the import/export balance accordingly.

The BoC trade statistics are publicly available[13] and cover a complete time series from 1990 to 2005. These statistics include information on imports and exports of thousands of commodities. After collecting information on annual flows of the more than 100 commodities identified by NPRA, Step 2 involves calculating the C content for each commodity from its chemical formula. In cases where the imports and exports were expressed in units of volume, rather than mass, they were converted to mass based on the commodities' densities.

Step 3 involves summing the net C imports/exports across all commodities. The results of this step are shown in Table A-45. As shown in the table, the United States has been a net exporter of chemical intermediates and products throughout the 1990 to 2005 period.

Table A-45: Net Exports of Petrochemical Feedstocks, 1990 – 2005 (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Net Exports	11.8	13.4	12.7	15.0	12.6	13.9	11.5	13.6	8.9	8.7	8.5	1.9	7.3	15.0	20.4	6.7

After adjusting for imports and exports, the C budget is adjusted for the quantity of C that is used in the Industrial Processes sector of the Inventory. Fossil fuels used for non-energy purposes in industrial processes—and for which C emissions and storage have been characterized through mass balance calculations and/or emission factors that directly link the non-energy use fossil fuel raw material and the industrial process product—are not included in the non-energy use sector. These industrial processes (and their non-energy use fossil fuel raw materials) include iron and steel (coal coke), primary aluminum (petroleum coke), titanium oxide (petroleum coke), ferroalloys (petroleum coke), and ammonia and urea (petroleum coke and natural gas).

For each year of the Inventory, the total C content of non-energy uses was calculated by starting with the EIA estimate of non-energy use, and reducing it by the adjustment factor for net exports (see Table A-45) to yield net domestic fuel consumption for non-energy. The balance was apportioned to either stored C or emissive C, based on a storage factor.

The overall storage factor for the feedstocks was determined by developing a mass balance on the C in feedstocks, and characterizing products, uses, and environmental releases as resulting in either storage or emissions. The total C in the system was estimated by multiplying net domestic consumption for non-energy by the C content of each of the feedstocks (i.e., industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha). C content values for the fuel feedstocks are discussed in Annexes 2.1 and 2.2.

Next, C pools and releases in a variety of industrial releases, energy recovery processes, and products were characterized. The C fate categories are plastics, energy recovery, synthetic rubber, synthetic fibers, organic solvents, C black, detergents and personal cleansers, industrial non-methane volatile organic compound (NMVOC)

[13] See the U.S International Trade Commission (USITC) Trade Dataweb at <http://dataweb.usitc.gov/>.

emissions, hazardous waste incineration, industrial toxic chemical (i.e., TRI) releases, pesticides, food additives, antifreeze and deicers (glycols), and silicones.[14]

The C in each product or waste produced was categorized as either stored or emitted. The aggregate storage factor is the C-weighted average of storage across fuel types. As discussed later in the section on uncertainty, the sum of stored C and emitted C (i.e., the outputs of the system) exceeded total C consumption (the inputs to the system) for some years in the time series.[15] To address this mass imbalance, the storage factor was calculated as C storage divided by total C outputs (rather than C storage divided by C inputs).

Note that the system boundaries for the storage factor do not encompass the entire life-cycle of fossil-based C consumed in the United States insofar as emissions of CO_2 from waste combustion are accounted for separately in the Inventory and are discussed in the Waste Combustion section of the Energy chapter.

The following sections provide details on the calculation steps, assumptions, and data sources employed in estimating and classifying the C in each product and waste shown in Table A-46. Summing the C stored and dividing it by total C outputs yields the overall storage factor, as shown in the following equation for 2005:

$$\text{Overall Storage Factor} = \text{C Stored} / (\text{C Stored} + \text{C Emitted}) =$$

$$146.2 \text{ Tg } CO_2 \text{ Eq.} / (146.2 + 92.9) \text{ Tg } CO_2 \text{ Eq.} = 61\%$$

Table A-46: C Stored and Emitted by Products from Feedstocks in 2005 (Tg CO_2 Eq.)

Product/Waste Type	C Stored (Tg CO_2 Eq.)	C Emitted (Tg CO_2 Eq.)
Industrial Releases	**0.4**	**5.3**
TRI Releases	0.4	1.0
Industrial VOCs		2.1
Non-combustion CO		0.7
Hazardous Waste Incin.		1.5
Energy Recovery		**71.9**
Products	**145.8**	**15.7**
Plastics	123.0	-
Synthetic Rubber	11.9	-
Abraded tire rubber	-	0.7
Synthetic Fiber	10.2	-
Pesticides	0.3	0.2
Soaps, shampoos, detergents	-	4.7
Food additives	-	0.9
Antifreeze and deicers	-	1.1
Silicones	0.5	-
Solvent VOCs	-	8.18
Total	**146.2**	**92.9**

- Not applicable
Note: Totals may not sum due to independent rounding.

The three categories of C accounted for in the table are industrial releases, energy recovery, and products. Each is discussed below.

[14] For the most part, the releases covered by the U.S. Toxic Release Inventory (TRI) represent air emissions or water discharges associated with production facilities. Similarly, VOC emissions are generally associated with production facilities. These emissions could have been accounted for as part of the Waste chapter, but because they are not necessarily associated with waste management, they were included here. Toxic releases are not a "product" category, but they are referred to as such for ease of discussion.

[15] Overall, there was fairly close agreement between inputs and outputs; for the entire 1990 through 2005 time series, inputs exceeded outputs by 1.6 percent. During the period 1990 through 1999, carbon inputs exceeded carbon outputs (i.e., the sum of carbon stored and carbon emitted), and for those years, the assumption was made that the "missing" carbon was lost through fates leading to emissions.

Industrial Releases

Industrial releases include toxic chemicals reported through the Toxics Release Inventory, industrial emissions of volatile organic compounds (VOCs), CO emissions (other than those related to fuel combustion), and emissions from hazardous waste incineration.

TRI Releases

Fossil-derived C is found in many toxic substances released by industrial facilities. The Toxics Release Inventory (TRI), maintained by EPA, tracks these releases by chemical and environmental release medium (i.e., land, air, or water) on a biennial basis (EPA 2000). By examining the C contents and receiving media for the top 35 toxic chemicals released, which account for 90 percent of the total mass of chemicals, the quantity of C stored and emitted in the form of toxic releases can be estimated.

The TRI specifies releases by chemical, so C contents were assigned to each chemical based on molecular formula. The TRI also classifies releases by disposal location as either off-site or on-site. The on-site releases are further subdivided into air emissions, surface water discharges, underground injection, and releases to land; the latter is further broken down to disposal in a RCRA Subtitle C (i.e., hazardous waste) landfill or to "Other On-Site Land Disposal."[16] The C released in each disposal location is provided in Table A-47.

Each on-site classification was assigned a storage factor. A one hundred percent storage factor was applied to disposition of C to underground injection and to disposal to RCRA-permitted landfills, while the other disposition categories were assumed to result in an ultimate fate of emission as CO_2 (i.e., a storage factor of zero was applied to these categories.) The release allocation is not reported for off-site releases; therefore, the approach was to develop a C-weighted average storage factor for the on-site C and apply it to the off-site releases.

For the remaining 10 percent of the TRI releases, the weights of all chemicals were added and an average C content value, based upon the top 35 chemicals' C contents, was applied. The storage and emission allocation for the remaining 10 percent of the TRI releases was carried out in the same fashion as for the 35 major chemicals.

Data on TRI releases for the full 1990 through 2005 time series were not readily available. Since this category is small (less than 1 Tg C emitted and stored), the 1998 value was applied for the entire time series.

Table A-47: 1998 TRI Releases by Disposal Location (Gg CO_2 Eq.)

Disposal Location	Carbon Stored (Gg CO_2 Eq.)	Carbon Emitted (Gg CO_2 Eq.)
Air Emissions	-	924.0
Surface Water Discharges	-	6.7
Underground Injection	89.4	-
RCRA Subtitle C Landfill Disposal	1.4	-
Other On-Site Land Releases	-	15.9
Off-site Releases	6.4	36.0
Total	**97.2**	**982.6**

- Not applicable
Note: Totals may not sum due to independent rounding.

Volatile Organic Compound Emissions from Industrial Processes and Solvent Evaporation Emissions

Data on annual non-methane volatile organic compound (NMVOC) emissions were obtained from the Air Emissions Trends Report data (EPA 2006a). The 1990-2005 Trends Report data include information on NMVOC emissions by end-use category; some of these fall into the heading of "industrial releases" in Table A-47 above, and others are related to "product use"; for ease of discussion, both are covered here. The end-use categories that represent "Industrial NMVOC Emissions" include chemical and allied products, metals processing, and other industrial processes. NMVOC emissions from solvent utilization (product use) were considered to be a result of non-energy use of petrochemical feedstocks. These categories were used to distinguish non-energy uses from

[16] Only the top 9 chemicals had their land releases separated into RCRA Landfills and Other Land Disposal. For the remaining chemicals, it was assumed that the ratio of disposal in these two categories was equal to the carbon-weighted average of the land disposal fate of the top 9 chemicals (i.e., 8 percent attributed to RCRA Landfills and 92 percent in the "Other" category).

energy uses; other categories where VOCs could be emitted due to combustion of fossil fuels were excluded to avoid double counting.

Because solvent evaporation and industrial NMVOC emission data are provided in tons of total NMVOCs, assumptions were made concerning the average C content of the NMVOCs for each category of emissions. The assumptions for calculating the C fraction of industrial and solvent utilization emissions were made separately and differ significantly. For industrial NMVOC emissions, a C content of 85 percent was assumed. This value was chosen to reflect the C content of an average volatile organic compound based on the list of the most abundant NMVOCs provided in the Trends Report. The list contains only pure hydrocarbons, including saturated alkanes (C contents ranging from 80 to 85 percent based upon C number), alkenes (C contents approximately 85.7 percent), and some aromatics (C contents approximately 90 percent, depending upon substitution).

An EPA solvent evaporation emissions dataset (Tooly 2001) was used to estimate the C content of solvent emissions. The dataset identifies solvent emissions by compound or compound category for six different solvent end-use categories: degreasing, graphic arts, dry cleaning, surface coating, other industrial processes, and non-industrial processes. The percent C of each compound identified in the dataset was calculated based on the molecular formula of the individual compound (e.g., the C content of methylene chloride is 14 percent; the C content of toluene is 91 percent). For solvent emissions that are identified in the EPA dataset only by chemical category (e.g., butanediol derivatives) a single individual compound was selected to represent each category, and the C content of the category was estimated based on the C content of the representative compound. The overall C content of the solvent evaporation emissions for 1998, estimated to be 56 percent, is assumed to be constant across the entire time series.

The results of the industrial and solvent NMVOC emissions analysis are provided in Table A-48 for 1990 through 2005. Solvent evaporation emissions in 2005 were 8.1 Tg CO_2 Eq., and industrial NMVOC emissions in 2005 were 2.1 Tg CO_2 Eq. In 2005, NMVOC and solvent activity data were revised across the entire time series to reflect updated information from the 2005 National Air Quality and Emissions Trends Report.

Table A-48: Industrial and Solvent NMVOC Emissions

	1990	1995	2000	2001	2002	2003	2004	2005
Industrial NMVOCs[a]								
NMVOCs ('000 Short Tons)	1,157	1,235	775	753	738	738	739	740
Carbon Content (%)	85%	85%	85%	85%	85%	85%	85%	85%
Carbon Emitted (Tg CO_2 Eq.)	3.3	3.5	2.2	2.1	2.1	2.1	2.1	2.1
Solvent Evaporation[b]								
Solvents ('000 Short Tons)	5,750	6,183	4,832	5,012	4,311	4,317	4,322	4,328
Carbon Content (%)	56%	56%	56%	56%	56%	56%	56%	56%
Carbon Emitted (Tg CO_2 Eq.)	10.8	11.6	9.0	9.4	8.1	8.1	8.1	8.1

[a] Includes emissions from chemical and allied products, petroleum and related industries, and other industrial processes categories.
[b] Includes solvent usage and solvent evaporation emissions from degreasing, graphic arts, dry cleaning, surface coating, other industrial processes, and non-industrial processes.

Non-Combustion Carbon Monoxide Emissions

Carbon monoxide (CO) emissions data were also obtained from the Air Emissions Trends Report data (EPA 2006a). There are three categories of CO emissions in the report that are classified as process-related emissions not related to fuel combustion. These include chemical and allied products manufacturing, metals processing, and other industrial processes. Some of these CO emissions are accounted for in the Industrial Processes section of this report, and are therefore not accounted for in this section. These include total C emissions from the primary aluminum, titanium dioxide, iron and steel, and ferroalloys production processes. The total C (CO and CO_2) emissions from oil and gas production, petroleum refining, and asphalt manufacturing are also accounted for elsewhere in this Inventory. Sustainably harvested biogenic emissions (e.g., pulp and paper process emissions) are also excluded from calculation of CO emissions in this section. Those CO emissions that are not accounted for elsewhere are considered to be byproducts of non-fuel use of feedstocks and are included in the calculation of the petrochemical feedstocks storage factor. Table A-49 lists the CO emissions that remain after taking into account the exclusions listed above.

Table A-49: Non-Combustion Carbon Monoxide Emissions[a]

Year	CO Emitted (Thousand Short Tons)	Carbon Emitted (Tg CO_2 Eq.)
1990	489	0.7
1991	441	0.6
1992	454	0.6
1993	486	0.7
1994	481	0.7
1995	481	0.7
1996	552	0.8
1997	570	0.8
1998	567	0.8
1999	605	0.9
2000	623	0.9
2001	650	0.9
2002	493	0.7
2003	499	0.7
2004	505	0.7
2005	511	0.7

[a] Includes emissions from chemical and allied products, petroleum and related industries, metals processing, and other industrial processes categories.

Hazardous Waste Incineration

Hazardous wastes are defined by the EPA under the Resource Conservation and Recovery Act (RCRA).[17] Industrial wastes, such as rejected products, spent reagents, reaction by-products, and sludges from wastewater or air pollution control, are federally regulated as hazardous wastes if they are found to be ignitable, corrosive, reactive, or toxic according to standardized tests or studies conducted by the EPA.

Hazardous wastes must be treated prior to disposal according to the federal regulations established under the authority of RCRA. Combustion is one of the most common techniques for hazardous waste treatment, particularly for those wastes that are primarily organic in composition or contain primarily organic contaminants. Generally speaking, combustion devices fall into two categories: incinerators that burn waste solely for the purpose of waste management, and boilers and industrial furnaces (BIFs) that burn waste in part to recover energy from the waste. More than half of the hazardous waste combusted in the United States is burned in BIFs; because these processes are included in the energy recovery calculations described below, they are not included as part of hazardous waste incineration.

EPA's Office of Solid Waste requires biennial reporting of hazardous waste management activities, and these reports provide estimates of the amount of hazardous waste burned for incineration or energy recovery. EPA stores this information in its Biennial Reporting System (BRS) database (EPA 2000a, 2004, 2006b). Combusted hazardous wastes are identified based on EPA-defined management system types M041 through M049

[17] [42 U.S.C. §6924, SDWA §3004]

(incineration). Combusted quantities are grouped into four representative waste form categories based on the form codes reported in the BRS: aqueous liquids, organic liquids and sludges, organic solids, and inorganic solids. To relate hazardous waste quantities to C emissions, "fuel equivalent" factors were derived for hazardous waste by assuming that the hazardous wastes are simple mixtures of a common fuel, water, and noncombustible ash. For liquids and sludges, crude oil is used as the fuel equivalent and coal is used to represent solids.

Fuel equivalent factors were multiplied by the tons of waste incinerated to obtain the tons of fuel equivalent. Multiplying the tons of fuel equivalent by the C content factors (discussed in Annex 2.2) yields tons of C emitted. Implied C content is calculated by dividing the tons of C emitted by the associated tons of waste incinerated.

Waste quantity data for hazardous wastes were obtained from EPA's BRS database for reporting years 1989, 1991, 1993, 1995, 1997, 1999, 2001, and 2003 (EPA 2000a, 2004, 2006b). Values for years after 2003 were held constant at the 2003 level. Combusted waste quantities were obtained from Form GM (Generation and Management) for wastes burned on site and Form WR (Wastes Received) for waste received from off-site for combustion. For each of the waste types, assumptions were developed on average waste composition (see Table A-50). Regulations require incinerators to achieve at least 99.99 percent destruction of organics; this formed the basis for assuming the fraction of C oxidized. Emissions from hazardous waste incineration in 2003 were 1.5 Tg CO_2 Eq. Table A-51 lists the CO_2 emissions from hazardous waste incineration.

Table A-50: Assumed Composition of Combusted Hazardous Waste by Weight (Percent)

Waste Type	Water (%)	Noncombustibles (%)	Fuel Equivalent (%)
Aqueous Waste	90	5	5
Organic Liquids and Sludges	40	20	40
Organic Solids	20	40	40
Inorganic Solids	20	70	10

Table A-51: CO_2 Emitted from Hazardous Waste Incineration (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
CO_2 Emissions	1.1	1.1	1.1	1.2	1.5	1.7	1.7	1.8	1.6	1.4	1.4	1.4	1.4	1.5	1.5	1.5

Energy Recovery

The amount of feedstocks combusted for energy recovery was estimated from data included in EIA's Manufacturers Energy Consumption Survey (MECS) for 1991, 1994, 1998, and 2002 (EIA 1994, 1997, 2001b, 2004). Some fraction of the fossil C exiting refineries and designated for use for feedstock purposes actually ends up being combusted for energy recovery (despite the designation of feedstocks as a "non-energy" use) because the chemical reactions in which fuel feedstocks are used are not 100 percent efficient. These chemical reactions may generate unreacted raw material feedstocks or generate byproducts that have a high energy content. The chemical industry and many downstream industries are energy-intensive and often have boilers or other energy recovery units on-site, and thus these unreacted feedstocks or byproducts are often combusted for energy recovery. Also, as noted above in the section on hazardous waste incineration, regulations provide a strong incentive—and in some cases require—burning of organic wastes generated from chemical production processes.

Information available from the MECS include data on the consumption for energy recovery of "other" fuels in the petroleum and coal products, chemicals, primary metals, nonmetallic minerals, and other manufacturing sectors. These "other" fuels include refinery still gas; waste gas; waste oils, tars, and related materials; petroleum coke, coke oven and blast furnace gases; and other uncharacterized fuels. Fuel use of petroleum coke is included separately in the fuel use data provided annually by EIA, and energy recovery of coke oven gas and blast furnace gas (i.e., byproducts of the iron and steel production process) is addressed in the Iron and Steel production section in the Industrial Processes chapter. Consumption of refinery still gas in the refinery sector is also included separately in the fuel use data from EIA. Consumption of net steam, assumed to be generated from fossil fuel combustion, is also included separately in the fuel use data from EIA. Therefore, these categories of "other" fuels are addressed elsewhere in the Inventory and not considered as part of the petrochemical feedstocks energy recovery analysis. The remaining categories of fuels, including waste gas; waste oils, tars, and related materials; and other uncharacterized fuels are assumed to be petrochemical feedstocks burned for energy recovery (see Table A-52). The conversion factors listed in Annex 2.1 were used to convert the Btu values for each fuel feedstock to Tg CO_2. Petrochemical feedstocks combusted for energy recovery corresponded to 42.7 Tg CO_2 Eq. in 1991, 35.8 Tg CO_2 Eq. in 1994, 58.7

Tg CO_2 Eq. in 1998, and 71.9 Tg CO_2 in 2002. Values for petrochemical feedstocks burned for energy recovery for years between 1991 and 1994, between 1994 and 1998, and between 1998 and 2002 have been estimated by interpolation. The value for 1990 is assumed to be the same as the value for 1991, and values for years subsequent to 2002 are assumed to be the same as the value for 2002 (Table A-53).

Table A-52: Summary of 2002 MECS Data for Other Fuels Used in Manufacturing/Energy Recovery (Trillion Btu)

Subsector and Industry	NAICS CODE	Waste Gas[a]	Waste Oils/Tars[b]	Refinery Still Gas[c]	Net Steam[d]	Other Fuels[e]
Printing and Related Support	323	0	0	0	0	1
Petroleum and Coal Products	324	0	2	1396	89	67
Chemicals	325	483	10	0	261	394
Plastics and Rubber Products	326	0	0	0	4	1
Nonmetallic Mineral Products	327	0	0	0	0	43
Primary Metals	331	1	1	0	31	4
Fabricated Metal Products	332	0	0	0	0	2
Machinery	333	0	0	0	2	2
Computer and Electronic Products	334	0	0	0	1	1
Electrical Equip., Appliances, Components	335	0	0	0	1	0
Transportation Equipment	336	1	0	0	7	18
Furniture and Related Products	337	0	8	0	1	2
Miscellaneous	339	0	0	0	1	1
Total (Trillion Btu)		**485**	**21**	**1396**	**397**	**536**
Average C Content (Tg/QBtu)		18.14	20.62	17.51	0	19.37
Fraction Oxidized		1	1	1	0	1
Total C (Tg)		**8.80**	**0.43**	**24.44**		**10.38**
Total C (Tg) (ex. still gas from refining)		**8.80**	**0.43**	**0.00**		**10.38**

[a] C content: Waste Gas is assumed to be same as naphtha <401 deg. F
[b] C content: Waste Oils/Tars is assumed to be same as asphalt/road oil
[c] Refinery "still gas" fuel consumption is reported elsewhere in the Inventory and is excluded from the total C content estimate
[d] Net steam fuel consumption is reported elsewhere in the Inventory and is excluded from the total C content estimate
[e] C content: "Other" is assumed to be the same as petrochemical feedstocks

Table A-53: Carbon Emitted from Fuels Burned for Energy Recovery (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
C Emissions	42.7	42.7	40.4	38.1	35.8	41.5	47.2	53.0	58.7	62.0	65.3	68.6	71.9	71.9	71.9	71.9

Products

More C is found in products than in industrial releases or energy recovery. The principal types of products are plastics; synthetic rubber; synthetic fiber; C black; pesticides; soaps, detergents, and cleansers; food additives; antifreeze and deicers (glycols); silicones; and solvents. Solvent evaporation was discussed previously along with industrial releases of NMVOCs; the other product types are discussed below.

Plastics

Data on annual production of plastics were taken from the American Plastics Council (APC), as published in *Chemical & Engineering News* and on the APC and Society of Plastics Industry (SPI) websites, and through direct communication with the APC (APC 2000, 2001, 2003, 2004, 2005, 2006; SPI 2000; Eldredge-Roebuck 2000). Production was organized by resin type (see Table A-54) and by year. Several of the resin categories included production from Canada and/or Mexico, in addition to the U.S. values for part of the time series. The production data for the affected resins and years were corrected using an economic adjustment factor, based on the percent of North American production value in this industry sector accounted for by the United States. A C content was then assigned for each resin. These C contents were based on molecular formulas and are listed in Table A-55 and Table A-56. In cases where the resin type is generic, referring to a group of chemicals and not a single polymer (e.g., phenolic resins, other styrenic resins), a representative compound was chosen. For engineering resins and other resins, a weighted C content of 68 percent was assumed (i.e., it was assumed that these resins had the same content as those for which a representative compound could be assigned).

There were no emissive uses of plastics identified, so 100 percent of the C was considered stored in products. However, an estimate of emissions related to the combustion of these plastics in the municipal solid waste stream can be found in the Waste Combustion section of the Energy chapter.

Table A-54: 2005 Plastic Resin Production (Tg dry weight) and C Stored (Tg CO_2 Eq.)

Resin Type	2005 Production[a] (Tg dry weight)	Carbon Stored (Tg CO_2 Eq.)
Epoxy	0.28	0.8
Urea	0.69	0.9
Melamine	0.69	0.7
Phenolic	1.94	5.4
Low-Density Polyethylene (LDPE)	3.24	10.2
Linear Low-Density Polyethylene (LLDPE)	4.92	15.5
High Density Polyethylene (HDPE)	6.68	21.0
Polypropylene (PP)	7.43	23.4
Acrylonitrile-butadiene-styrene (ABS)	0.49	1.5
Other Styrenics [c]	0.74	2.5
Polystyrene (PS)	2.60	8.8
Nylon	0.50	1.2
Polyvinyl chloride (PVC) [b]	6.31	8.9
Thermoplastic Polyester	3.07	7.0
Engineering Resins	1.04	2.6
All Other (including Polyester (unsaturated))	5.02	12.5
Total	**45.66**	**123.0**

[a] Originally included production from Canada for Urea, Melamine, LDPE, LLDPE, HDPE, PP, ABS, SAN, Phenolic, Other Styrenics, PS, Nylon, PVC, Thermoplastic Polyester, and Engineering Resins, and production from Mexico for ABS, SAN, Other Styrenics, Nylon, and Thermoplastic Polyester. Values have been adjusted to account just for U.S. production.
[b] Includes copolymers
[c] Includes Styrene-acrylonitrile (SAN)
Note: Totals may not sum due to independent rounding.

Table A-55: Assigned C Contents of Plastic Resins (% by weight)

Resin Type	C Content	Source of C Content Assumption
Epoxy	76%	Typical epoxy resin made from epichlorhydrin and bisphenol A
Polyester (Unsaturated)	63%	Poly (ethylene terephthalate) (PET)
Urea	34%	50% carbamal, 50% N-(hydroxymethyl) urea *
Melamine	29%	Trimethylol melamine *
Phenolic	77%	Phenol
Low-Density Polyethylene (LDPE)	86%	Polyethylene
Linear Low-Density Polyethylene (LLDPE)	86%	Polyethylene
High Density Polyethylene (HDPE)	86%	Polyethylene
Polypropylene (PP)	86%	Polypropylene
Acrylonitrile-Butadiene-Styrene (ABS)	85%	50% styrene, 25% acrylonitrile, 25% butadiene
Styrene-Acrylonitrile (SAN)	80%	50% styrene, 50% acrylonitrile
Other Styrenics	92%	Polystyrene
Polystyrene (PS)	92%	Polystyrene
Nylon	65%	Average of nylon resins (see **Error! Reference source not found.**)
Polyvinyl Chloride (PVC)	38%	Polyvinyl chloride
Thermoplastic Polyester	63%	Polyethylene terephthalate
Engineering Resins	68%	Weighted average of other resin production
All Other	68%	Weighted average of other resin production

*Does not include alcoholic hydrogens.

Table A-56: Major Nylon Resins and their C Contents (% by weight)

Resin	C Content
Nylon 6	64%
Nylon 6,6	64%
Nylon 4	52%
Nylon 6,10	68%
Nylon 6,11	69%
Nylon 6,12	70%
Nylon 11	72%

Synthetic Rubber

Data on synthetic rubber in tires were derived from data on the scrap tire market and the composition of scrap tires from the Rubber Manufacturers' Association's (RMA) Scrap Tire Management Council (STMC). The market information is presented in the report *Scrap Tire Markets in the United States 2005 Edition* (RMA 2006), while the tire composition information is from the "Scrap Tires, Facts and Figures" section of the organization's website (STMC 2003). Data on synthetic rubber in other products (durable goods, nondurable goods, and containers and packaging) were obtained from EPA's *Municipal Solid Waste in the United States* reports (1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, and 2005) and detailed unpublished backup data for some years not shown in the *Characterization of Municipal Solid Waste in the United States* reports (Schneider 2007). The abraded rubber from scrap passenger tires was assumed to be 5 lbs per scrap tire, while the abraded rubber from scrap truck tires was assumed to be 20 lbs per scrap tire. Data on abraded rubber weight were obtained by calculating the average weight difference between new and scrap tires (STMC 2003).

A C content for synthetic rubber (90 percent for tire synthetic rubber and 85 percent for non-tire synthetic rubber) was assigned based on the weighted average of C contents (based on molecular formula) by elastomer type consumed in 1998, 2001, and 2002 (see **Error! Reference source not found.**). The 1998 consumption data were obtained from the International Institute of Synthetic Rubber Producers (IISRP) press release "Synthetic Rubber Use Growth to Continue Through 2004, Says IISRP and RMA" (IISRP 2000). The 2001 and 2002 consumption data were obtained from the IISRP press release, "IISRP Forecasts Moderate Growth in North America to 2007" (IISRP 2003).

The rubber in tires that is abraded during use (the difference between new tire and scrap tire rubber weight) was considered to be 100 percent emitted. Other than abraded rubber, there were no emissive uses of scrap tire and non-tire rubber identified, so 100 percent of the non-abraded amount was assumed stored. Emissions related to the combustion of rubber in scrap tires and consumer goods can be found in the Waste Combustion section of the Energy chapter.

Table A-57: 2002 Rubber Consumption (Gg) and C Content (%)

Elastomer Type	2002 Consumption (Gg)*	C Content
SBR Solid	768	91%
Polybutadiene	583	89%
Ethylene Propylene	301	86%
Polychloroprene	54	59%
NBR Solid	84	77%
Polyisoprene	58	88%
Others	367	88%
Weighted Average	**-**	**90%**
Total	**2,215**	**-**

* Includes consumption in Canada.
- Not applicable
Note: Totals may not sum due to independent rounding.

Synthetic Fibers

Annual synthetic fiber production data were obtained from the Fiber Economics Bureau, as published in *Chemical & Engineering News* (APC 2001, 2003, 2005, and 2006). These data are organized by year and fiber type. For each fiber, a C content was assigned based on molecular formula (see **Error! Reference source not found.**). For polyester, the C content for poly(ethylene terephthalate) (PET) was used as a representative compound. For nylon, the average C content of nylon 6 and nylon 6,6 was used, since these are the most widely produced nylon fibers. Cellulosic fibers, such as acetate and rayon, have been omitted from the synthetic fibers' C accounting because much of their C is of biogenic origin. These fibers account for only 4 percent of overall fiber production by weight.

There were no emissive uses of fibers identified, so 100 percent of the C was considered stored. Note that emissions related to the combustion of textiles in municipal solid waste are accounted for under the Waste Combustion section of the Energy chapter.

Table A-58: 2005 Fiber Production (Tg), C Content (%), and C Stored (Tg CO_2 Eq.)

Fiber Type	Production (Tg)	C Content	C Stored (Tg CO_2 Eq.)
Polyester	1.4	63%	3.14
Nylon	1.1	64%	2.53
Olefin	1.4	86%	4.40
Acrylic	0.1	68%	0.16
Total	**3.9**	**-**	**10.22**

- Not applicable
Note: Totals may not sum due to independent rounding

Pesticides

Pesticide consumption data were obtained from the *1994/1995, 1996/1997, 1998/1999, and 2000/2001 Pesticides Industry Sales and Usage Market Estimates* (EPA 1998b, 1999b, 2002c, 2004b) reports. The most recent data available were for 2001, so it was assumed that the 2002 through 2005 consumption was equal to that of 2001. Active ingredient compound names and consumption weights were available for the top 25 agriculturally-used pesticides and top 10 pesticides used in the home and garden and the industry/commercial/government categories. The report provides a range of consumption for each active ingredient; the midpoint was used to represent actual consumption. Each of these compounds was assigned a C content value based on molecular formula. If the compound contained aromatic rings substituted with chlorine or other halogens, then the compound was considered persistent and the C in the compound was assumed to be stored. All other pesticides were assumed to release their C to the atmosphere. Over one-third of 2002 total pesticide active ingredient consumption was not specified by chemical type in the *Sales and Usage* report (EPA 2004b). This unspecified portion of the active ingredient consumption was treated as a single chemical and assigned a C content and a storage factor based on the weighted average of the known chemicals' values.

Table A-59: Active Ingredient Consumption in Pesticides (Million lbs.) and C Emitted and Stored (Tg CO_2 Eq.) in 2001

Pesticide Use*	Active Ingredient (Million lbs.)	C Emitted (Tg CO_2 Eq.)	C Stored (Tg CO_2 Eq.)
Agricultural Uses [a]	458.5	0.1	0.2
Non-Agricultural Uses [b]	84.5	+	+
Home & Garden	38.5	+	+
Industry/Gov't/Commercial	46.0	+	+
Other	345.0	0.1	0.1
Total	**888.0**	**0.2**	**0.3**

+ Less than 0.05 Tg CO_2 Eq.
*2001 estimates (EPA 2004b).
Note: Totals may not sum due to independent rounding.

Soaps, Shampoos, and Detergents

Cleansers—soaps, shampoos, and detergents—are among the major consumer products that may contain fossil C. All of the C in cleansers was assumed to be fossil-derived, and, as cleansers eventually biodegrade, all of the C was assumed to be emitted. The first step in estimating C flows was to characterize the "ingredients" in a sample of cleansers. For this analysis, cleansers were limited to the following personal household cleaning products: bar soap, shampoo, laundry detergent (liquid and granular), dishwasher detergent, and dishwashing liquid. Data on the annual consumption of household personal cleansers were obtained from the U.S. Census Bureau 1992, 1997, and 2002 Economic Census. Consumption values for 1990 and 1991 were assumed to be the same as the 1992 value; consumption was interpolated between 1992 and 1997 and between 1997 and 2002; consumption for 2003 through 2005 was assumed to equal the 2002 value.

Chemical formulae were used to determine C contents (as percentages) of the ingredients in the cleansers. Each product's overall C content was then derived from the composition and contents of its ingredients. From these values the mean C content for cleansers was calculated to be 21.9 percent.

The Census Bureau presents consumption data in terms of quantity (in units of million gallons or million pounds) and/or terms of value (thousands of dollars) for eight specific categories, such as "household liquid laundry detergents, heavy duty" and "household dry alkaline automatic dishwashing detergents." Additionally, the report provides dollar values for the total consumption of "soaps, detergents, etc.—dry" and "soaps, detergents, etc.—liquid." The categories for which both quantity and value data are available is a subset of total production. Those categories that presented both quantity and value data were used to derive pounds per dollar and gallons per dollar conversion rates, and they were extrapolated (based on the Census Bureau estimate of total value) to estimate the total quantity of dry and liquid[18] cleanser categories, respectively.

Next, the total tonnage of cleansers was calculated (wet and dry combined). Multiplying the mean C content (21.9 percent) by this value yielded an estimate of 4.5 Tg CO_2 Eq. in cleansers for 1997. For 1992 and 2002 the estimates are 3.6 Tg CO_2 Eq. and 5.1 Tg CO_2 Eq. Estimates for other years are based on these values as described above, and are shown in **Error! Reference source not found.**.

Table A-60: C Emitted from Utilization of Soaps, Shampoos, and Detergents (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
C Emissions	3.6	3.6	3.6	3.8	4.0	4.2	4.3	4.5	4.5	4.2	4.3	4.7	5.1	4.8	4.7	4.7

Antifreeze and Deicers

Glycol compounds, including ethylene glycol, propylene glycol, diethylene glycol, and triethylene glycol, are used as antifreeze in motor vehicles, deicing fluids for commercial aircraft, and other similar uses. These glycol compounds are assumed to ultimately enter wastewater treatment plants where they are degraded by the wastewater treatment process to CO_2 or to otherwise biodegrade to CO_2. Glycols are water soluble and degrade rapidly in the environment (Howard 1993).

Annual production data for each glycol compound used as antifreeze and deicers were obtained from the Guide to the Business of Chemistry, (American Chemistry Council 2005, 2006). Import and export data were used to adjust annual production data to annual consumption data. The percentage of the annual consumption of each glycol compound used for antifreeze and deicing applications was estimated from Chemical Profiles data published on The Innovation Group website and from similar data published in the Chemical Market Reporter.

The consumption of glycol compounds in antifreeze and deicing applications is assumed to be 100 percent emitted as CO_2. Emissions of CO_2 from utilization of antifreeze and deicers are summarized in **Error! Reference source not found.**.

Table A-61: C Emitted from Utilization of Antifreeze and Deicers (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
C Emissions	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.1	1.1	1.2	1.3	1.1

Food Additives

Petrochemical feedstocks are used to manufacture synthetic food additives, including preservatives, flavoring agents, and processing agents. These compounds include glycerin, propylene glycol, benzoic acid, and other compounds. These compounds are incorporated into food products, and are assumed to ultimately enter wastewater treatment plants where they are degraded by the wastewater treatment processes to CO_2 or to otherwise biodegrade to CO_2. Certain food additives, e.g., glycerin, are manufactured both from petrochemical feedstocks and from biogenic feedstocks. Food additives that are derived from biogenic feedstocks are not considered in this analysis.

Annual production data for food additive compounds were obtained from the Guide to the Business of Chemistry (American Chemistry Council 2005, 2006). Import and export data were used to adjust annual production data to annual consumption data. The percentage of the annual consumption of food additive compounds

[18] A density of 1.05 g/mL—slightly denser than water—was assumed for liquid cleansers.

was estimated from Chemical Profiles data published on The Innovation Group website (<http://www.the-innovation-group.com/ChemProfiles>). The consumption of synthetic food additives is assumed to be 100 percent emitted as CO_2. Emissions of CO_2 from utilization of synthetic food additives are summarized in **Error! Reference source not found.**.

Table A-62: C Emitted from Utilization of Food Additives (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Emissions	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9

Silicones

Silicone compounds (e.g., polymethyl siloxane) are used as sealants and in manufactured products. Silicone compounds are manufactured from petrochemical feedstocks including methyl chloride. It is assumed that petrochemical feedstocks used to manufacture silicones are incorporated into the silicone products and not emitted as CO_2 in the manufacturing process. It is also assumed that the C contained in the silicone products is stored, and not emitted as CO_2.

Annual production data for each silicone manufacturing compound were obtained from the Guide to the Business of Chemistry (American Chemistry Council 2005, 2006). Import and export data were used to adjust annual production data to annual consumption data. The percentage of the annual consumption of each silicone manufacturing compound was estimated from Chemical Profiles data published on The Innovation Group website (<http://www.the-innovation-group.com/ChemProfiles>). The consumption of silicone manufacturing compounds is assumed to be 100 percent stored, and not emitted as CO_2. Storage of silicone manufacturing compounds is summarized in **Error! Reference source not found.**.

Table A-63: C Stored in Silicone Products (Tg CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
C Storage	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5

Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the feedstocks C storage factor and the quantity of C emitted from feedstocks in 2005. The Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for production data (the majority of the variables) were assumed to exhibit a normal distribution with a relative error of ±20 percent in the underlying EIA estimates, plus an additional ±15 percent to account for uncertainty in the assignment of imports and exports. An additional 10 percent (for a total of ±45 percent) was applied to the production of other oils (>401 deg. F) to reflect the additional uncertainty in the assignment of part of the production quantity to industrial processes. A relatively narrow uniform distribution ±1 percent to ±10 percent, depending on the fuel type) was applied to each C coefficient.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 61.0 percent, with a standard deviation of 1 percent and 95 percent confidence limits of 59 percent and 63 percent. This compares to the calculated estimate, used in the Inventory, of 61.1 percent. The analysis produced a C emission distribution approximating a normal curve with a mean of 81.6 Tg CO_2 Eq., standard deviation of 8.3 Tg CO_2 Eq., and 95 percent confidence limits of 65.4 and 98.1 Tg CO_2 Eq. This compares with a calculated estimate of 81.9 Tg CO_2 Eq.

The apparently tight confidence limits for the storage factor and C storage probably understate uncertainty, as a result of the way this initial analysis was structured. As discussed above, the storage factor for feedstocks is based on an analysis of six fates that result in long-term storage (e.g., plastics production), and eleven that result in emissions (e.g., volatile organic compound emissions). Rather than modeling the total uncertainty around all 17 of these fate processes, the current analysis addresses only the storage fates, and assumes that all C that is not stored is emitted. As the production statistics that drive the storage factors are relatively well-characterized, this approach yields a result that is probably biased toward understating uncertainty.

As far as specific sources of uncertainty, there are several cross-cutting factors that pervade the characterization of C flows for feedstocks. The aggregate storage factor for petrochemical feedstocks (industrial other coal, natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha) is based on assuming that the ultimate fates of all of these fuel types —in terms of storage and emissions—are similar. In addition, there are uncertainties associated with the simplifying assumptions made for each end use category C estimate. Generally, the estimate for a product is subject to one or both of the following uncertainties:

- The value used for estimating the C content has been assumed or assigned based upon a representative compound.
- The split between C storage and emission has been assumed based on an examination of the environmental fate of the products in each end use category.
- Environmental fates leading to emissions are assumed to operate rapidly, i.e., emissions are assumed to occur within one year of when the fossil C enters the non-energy mass balance. Some of the pathways that lead to emissions as CO_2 may take actually place on a time-scale of several years or decades. By attributing the emissions to the year in which the C enters the mass balance (i.e., the year in which it leaves refineries as a non-energy fuel use and thus starts being tracked by EIA), this approach has the effect of "front-end loading" the emission profile.

Another cross-cutting source of uncertainty is that for several sources the amount of C stored or emitted was calculated based on data for only a single year. This specific year may not be representative of storage for the entire Inventory period. Sources of uncertainty associated with specific elements of the analysis are discussed below.

Import and export data for petrochemical feedstocks were obtained from EIA, the National Petroleum Refiners Association, and the U.S. BoC for the major categories of petrochemical feedstocks (EIA 2001a, NPRA 2001, and U.S. BoC 2006). The complexity of the organic chemical industry, with multiple feedstocks, intermediates, and subtle differences in nomenclature, makes it difficult to ensure that the adjustments to the EIA data for imports and exports is accurate and the approach used here may underestimate or overestimate net exports of C.

Oxidation factors have been applied to non-energy uses of petrochemical feedstocks in the same manner as for energy uses. However, for those fuels where IPCC storage factors are used, this "oxidation factor" may be inherent in the storage factor applied when calculating emissions from non-energy consumption, which would result in a double-counting of the unoxidized C. Oxidation factors are small corrections, on the order of 1 percent, and therefore application of oxidation factors to non-energy uses may result in a slight underestimation of C emissions from non-energy uses.

The major uncertainty in using the TRI data are the possibility of double counting of emissions that are already accounted for in the NMVOC data (see above) and in the storage and emission assumptions used. The approach for predicting environmental fate simplifies some complex processes, and the balance between storage and emissions is very sensitive to the assumptions on fate. Extrapolating from known to unknown characteristics also introduces uncertainty. The two extrapolations with the greatest uncertainty are: 1) that the release media and fate of the off-site releases were assumed to be the same as for on-site releases, and 2) that the C content of the least frequent 10 percent of TRI releases was assumed to be the same as for the chemicals comprising 90 percent of the releases. However, the contribution of these chemicals to the overall estimate is small. The off-site releases only account for 3 percent of the total releases, by weight, and, by definition, the less frequent compounds only account for 10 percent of the total releases.

The principal sources of uncertainty in estimating CO_2 emissions from solvent evaporation and industrial NMVOC emissions are in the estimates of (a) total emissions and (b) their C content. Solvent evaporation and industrial NMVOC emissions reported by EPA are based on a number of data sources and emission factors, and may underestimate or overestimate emissions. The C content for solvent evaporation emissions is calculated directly from the specific solvent compounds identified by EPA as being emitted, and is thought to have relatively low uncertainty. The C content for industrial emissions has more uncertainty, however, as it is calculated from the average C content of an average volatile organic compound based on the list of the most abundant measured NMVOCs provided in EPA (2002a).

Uncertainty in the hazardous waste combustion analysis is introduced by the assumptions about the composition of combusted hazardous wastes, including the characterization that hazardous wastes are similar to mixtures of water, noncombustibles, and fuel equivalent materials. Another limitation is the assumption that all of the C that enters hazardous waste combustion is emitted—some small fraction is likely to be sequestered in combustion ash—but given that the destruction and removal efficiency for hazardous organics is required to meet or exceed 99.99 percent, this is a very minor source of uncertainty. C emission estimates from hazardous waste should be considered central value estimates that are likely to be accurate to within ±50 percent.

The amount of feedstocks combusted for energy recovery was estimated from data included in the Manufacturers Energy Consumption Surveys (MECS) for 1991, 1994, 1998, and 2002 (EIA 1994, 1997, 2001b, 2004). MECS is a comprehensive survey that is conducted every four years and intended to represent U.S. industry as a whole, but because EIA does not receive data from all manufacturers (i.e., it is a sample rather than a census), EIA must extrapolate from the sample. Also, the "other" fuels are identified in the MECS data in broad categories, including refinery still gas; waste gas; waste oils, tars, and related materials; petroleum coke, coke oven and blast furnace gases; and other uncharacterized fuels. Moreover, the industries using these "other" fuels are also identified only in broad categories, including the petroleum and coal products, chemicals, primary metals, nonmetallic minerals, and other manufacturing sectors. The "other" fuel consumption data are reported in BTUs (energy units) and there is uncertainty concerning the selection of a specific conversion factor for each broad "other" fuel category to convert energy units to mass units. Taken as a whole, the estimate of energy recovery emissions probably introduces more uncertainty than any other element of the non-energy analysis.

Uncertainty in the C storage estimate for plastics arises primarily from three factors. First, the raw data on production for several resins include Canadian and/or Mexican production and may overestimate the amount of plastic produced from U.S. fuel feedstocks; this analysis includes adjustments to "back out" the Canadian and Mexican values, but these adjustments are approximate. Second, the assumed C content values are estimates for representative compounds, and thus do not account for the many formulations of resins available. This uncertainty is greater for resin categories that are generic (e.g., phenolics, other styrenics, nylon) than for resins with more specific formulations (e.g., polypropylene, polyethylene). Lastly, the assumption that all of the C contained in plastics is stored ignores certain end uses (e.g., adhesives and coatings) where the resin may be released to the atmosphere; however, these end uses are likely to be small relative to use in plastics.

The quantity of C stored in synthetic rubber only accounts for the C stored in scrap tire synthetic rubber. The value does not take into account the rubber stored in other durable goods, clothing, footwear, and other non-durable goods, or containers and packaging. This adds uncertainty to the total mass balance of C stored. There are also uncertainties as to the assignment of C content values; however, they are much smaller than in the case of plastics. There are probably fewer variations in rubber formulations than in plastics, and the range of potential C content values is much narrower. Lastly, assuming that all of the C contained in rubber is stored ignores the possibility of volatilization or degradation during product lifetimes. However, the proportion of the total C that is released to the atmosphere during use is probably negligible.

A small degree of uncertainty arises from the assignment of C content values; however, the magnitude of this uncertainty is less than that for plastics or rubber. Although there is considerable variation in final textile products, the stock fiber formulations are standardized and proscribed explicitly by the Federal Trade Commission.

For pesticides, the largest source of uncertainty involves the assumption that an active ingredient's C is either 0 percent stored or 100 percent stored. This split is a generalization of chemical behavior, based upon active-ingredient molecular structure, and not on compound-specific environmental data. The mechanism by which a compound is bound or released from soils is very complicated and can be affected by many variables, including the type of crop, temperature, application method, and harvesting practice. Another smaller source of uncertainty arises from the C content values applied to the unaccounted for portion of active ingredient. C contents vary widely among pesticides, from 7 to 72 percent, and the remaining pesticides may have a chemical make-up that is very different from the 32 pesticides that have been examined. Additionally, pesticide consumption data were only available for 1987, 1993, 1995, 1997, 1999, and 2001; the majority of the time series data were interpolated or held constant at the latest (2001) value. Another source of uncertainty is that only the "active" ingredients of pesticides are considered in the calculations; the "inactive" ingredients may also be derived from petrochemical feedstocks.

It is important to note that development of this uncertainty analysis is a multi-year process. The current feedstocks analysis examines NEU fuels that end in storage fates Thus only C stored in pesticides, plastics, synthetic fibers, synthetic rubbers, silicones, and TRI releases to underground injection and Subtitle C landfills is accounted for in the uncertainty estimate above. In the future this analysis will be expanded to include the uncertainty surrounding emitted fates in addition to the storage fates. Estimates of variable uncertainty will also be refined where possible to include fewer assumptions. With these major changes in future Inventories, the uncertainty estimate is expected to change, and likely increase. An increase in the uncertainty estimate in the coming years will not indicate that the Inventory calculations have become less certain, but rather that the methods for estimating uncertainty have become more comprehensive; thus, potential future changes in the results of this analysis will reflect a change in the uncertainty analysis, not a change in the Inventory quality.

Asphalt and Road Oil

Asphalt is one of the principal non-energy uses of fossil fuels. The term "asphalt" generally refers to a mixture of asphalt cement and a rock material aggregate, a volatile petroleum distillate, or water. For the purposes of this analysis, "asphalt" is used interchangeably with asphalt cement, a residue of crude oil. According to EPA (2000e), approximately 100 Tg CO_2 Eq. has been used in the production of asphalt cement annually. Though minor amounts of C are emitted during production, asphalt has an overall C storage factor of almost 100 percent, as discussed below.

Paving is the primary application of asphalt cement, comprising 86 percent of production. The three types of asphalt paving produced in the United States are hot mix asphalt (HMA), cut-backs, and emulsified asphalt. HMA, which makes up 90 percent of total asphalt paving (EPA 2000c), contains asphalt cement mixed with an aggregate of rock materials. Cut-back asphalt is composed of asphalt cement thinned with a volatile petroleum distillate (e.g., naphtha). Emulsified asphalt contains only asphalt cement and water. Roofing products are the other significant end use of asphalt cement, accounting for approximately 14 percent of U.S. production (Kelly 2000). No data were available on the fate of C in asphalt roofing; it was assumed that it has the same fate as C in asphalt paving applications.

Methodology and Data Sources

A C storage factor was calculated for each type of asphalt paving. The fraction of C emitted by each asphalt type was multiplied by consumption data for asphalt paving (EPA 2000c, EIIP 1998) to estimate a weighted average C storage factor for asphalt as a whole.

The fraction of C emitted by HMA was determined by first calculating the organic emissions (volatile organic compounds [VOCs], carbon monoxide [CO], polycyclic aromatic hydrocarbons [PAHs], hazardous air pollutants [HAPs], and phenol) from HMA paving, using emission factors reported in EPA (2000e) and total HMA production.[19] The next step was to estimate the C content of the organic emissions. This calculation was based on the C content of CO and phenol, and an assumption of 85 percent C content for PAHs and HAPs. The C content of asphalt paving is a function of (1) the proportion of asphalt cement in asphalt paving, assumed to be 5 percent asphalt cement content based on personal communication with an expert from the National Asphalt Paving Association (Connolly 2000), and (2) the proportion of C in asphalt cement. For the latter factor, all paving types were characterized as having a mass fraction of 85 percent C in asphalt cement, based on the assumption that asphalt is primarily composed of saturated paraffinic hydrocarbons. By combining these estimates, the result is that over 99.99 percent of the C in asphalt cement was retained (i.e., stored), and less than 0.01 percent was emitted.

Cut-back asphalt is produced in three forms (i.e., rapid, medium and slow cure). All three forms emit C only from the volatile petroleum distillate used to thin the asphalt cement (EPA 1995). Because the petroleum distillates are not included in the EIA fuel use statistics for asphalt, the storage factor for cut-back is assumed to be 100 percent.

It was also assumed that there was no loss of C from emulsified asphalt (i.e., the storage factor is 100 percent) based on personal communication with an expert from Akzo Nobel Coatings, Inc. (James 2000).

Data on asphalt and road oil consumption and C content factors were supplied by EIA. Hot mix asphalt production and emissions factors were obtained from "Hot Mix Asphalt Plants Emissions Assessment Report" from EPA's *AP-42* (EPA 2000e) publication. The asphalt cement content of HMA was provided by Una Connolly of

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[19] The emission factors are expressed as a function of asphalt paving tonnage (i.e., including the rock aggregate as well as the asphalt cement).

National Asphalt Paving Association (Connolly 2000). The consumption data for cut-back and emulsified asphalts were taken from a Moulthrop, et al. study used as guidance for estimating air pollutant emissions from paving processes (EIIP 1998). "Asphalt Paving Operation" *AP-42* (EPA 1995) provided the emissions source information used in the calculation of the C storage factor for cut-back asphalt. The storage factor for emulsified asphalt was provided by Alan James of Akzo Nobel Coatings, Inc. (James 2000).

Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the asphalt C storage factor and the quantity of C stored in asphalt in 2005. The Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for asphalt production were assumed to be ±20 percent, while the asphalt property variables were assumed to have narrower distributions. A narrow uniform distribution, with maximum 5 percent uncertainty around the mean, was applied to the C content coefficient.

The Monte Carlo analysis, given a 95 percent confidence interval, produced a storage factor distribution that approximates a normal curve skewed to the right, around a mean of 99.6 percent, with a standard deviation less than 0.05 percent and boundaries between 99.3 and 99.8 percent. This compares to the storage factor value used in the Inventory of 100 percent. The analysis produced an emission distribution, skewed to the left, with an uncertainty range slightly below 100 percent. The emission uncertainty range is not applicable since the Inventory calculation estimates that zero C is emitted from asphalts and road oil.

The principal source of uncertainty is that the available data are from short-term studies of emissions associated with the production and application of asphalt. As a practical matter, the cement in asphalt deteriorates over time, contributing to the need for periodic re-paving. Whether this deterioration is due to physical erosion of the cement and continued storage of C in a refractory form or physicochemical degradation and eventual release of CO_2 is uncertain. Long-term studies may reveal higher lifetime emissions rates associated with degradation.

Many of the values used in the analysis are also uncertain and are based on estimates and professional judgment. For example, the asphalt cement input for hot mix asphalt was based on expert advice indicating that the range is variable—from about 3 to 5 percent—with actual content based on climate and geographical factors (Connolly 2000). Over this range, the effect on the calculated C storage factor is minimal (on the order of 0.1 percent). Similarly, changes in the assumed C content of asphalt cement would have only a minor effect.

The consumption figures for cut-back and emulsified asphalts are based on information reported for 1994. More recent trends indicate a decrease in cut-back use due to high VOC emission levels and a related increase in emulsified asphalt use as a substitute. However, because the C storage factor of each is 100 percent, use of more recent data would not affect the overall result.

Future improvements to this uncertainty analysis, and to the overall estimation of a storage factor for asphalt, include characterizing the long-term fate of asphalt.

Lubricants

Lubricants are used in industrial and transportation applications. They can be subdivided into oils and greases, which differ in terms of physical characteristics (e.g., viscosity), commercial applications, and environmental fate. According to EIA (2006), the C content from U.S. production of lubricants in 2005 was approximately 6.5 Tg C. Based on apportioning oils and greases to various environmental fates, and characterizing those fates as resulting in either long-term storage or emissions, the overall C storage factor was estimated to be 9 percent; thus, emissions in 2005 were about 5.9 Tg C, or 21.6 Tg CO_2 Eq.

Methodology and Data Sources

For each lubricant category, a storage factor was derived by identifying disposal fates and applying assumptions as to the disposition of the C for each practice. An overall lubricant C storage factor was calculated by taking a production-weighted average of the oil and grease storage factors.

Oils

Regulation of used oil in the United States has changed dramatically over the past 20 years.[20] The effect of these regulations and policies has been to restrict landfilling and dumping, and to encourage collection of used oil. The economics of the petroleum industry have generally not favored re-refining—instead, most of the used oil that has been collected has been combusted.

Error! Reference source not found. provides an estimated allocation of the fates of lubricant oils (Rinehart 2000), along with an estimate of the proportion of C stored in each fate. The ultimate fate of the majority of oils (about 84 percent) is combustion, either during initial use or after collection as used oil. Combustion results in 99 percent oxidation to CO_2 (EIIP 1999), with correspondingly little long-term storage of C in the form of ash. Dumping onto the ground or into storm sewers, primarily by "do-it-yourselfers" who change their own oil, is another fate that results in conversion to CO_2 given that the releases are generally small and most of the oil is biodegraded (based on the observation that land farming—application to soil—is one of the most frequently used methods for degrading refinery wastes). In the landfill environment, which tends to be anaerobic within municipal landfills, it is assumed that 90 percent of the oil persists in an underrated form, based on analogy with the persistence of petroleum in native petroleum-bearing strata, which are both anaerobic. Re-refining adds a recycling loop to the fate of oil. Re-refined oil was assumed to have a storage factor equal to the weighted average for the other fates (i.e., after re-refining, the oil would have the same probability of combustion, landfilling, or dumping as virgin oil), that is, it was assumed that about 97 percent of the C in re-refined oil is ultimately oxidized. Because of the dominance of fates that result in eventual release as CO_2, only about 3 percent of the C in oil lubricants goes into long-term storage.

Table A-64: Commercial and Environmental Fate of Oil Lubricants (Percent)

Fate of Oil	Portion of Total Oil	C Stored
Combusted During Use	**20**	**1**
Not Combusted During Use	**80**	**-**
Combusted as Used Oil *	64	1
Dumped on the ground or in storm sewers	6	0
Landfilled	2	90
Re-refined into lube oil base stock and other products	8	3
Weighted Average	**-**	**2.9**

* (e.g., in boilers or space heaters)
- Not applicable

Greases

Error! Reference source not found. provides analogous estimates for lubricant greases. Unlike oils, grease is generally not combusted during use, and combustion for energy recovery and re-refining is thought to be negligible. Although little is known about the fate of waste grease, it was assumed that 90 percent of the non-combusted portion is landfilled, and the remainder is dumped onto the ground or storm sewers. Because much of the waste grease will be in containers that render it relatively inaccessible to biodegradation, and because greases contain longer chain paraffins, which are more persistent than oils, it was assumed that 90 percent and 50 percent of the C in landfilled and dumped grease, respectively, would be stored. The overall storage factor is 82 percent for grease.

[20] For example, the U.S. EPA "RCRA (Resource Conservation and Recovery Act) On-line" web site (<http://www.epa.gov/rcraonline/>) has over 50 entries on used oil regulation and policy for 1994 through 2000.

Table A-65: Commercial and Environmental Fate of Grease Lubricants (Percent)

Fate of Grease	Portion of Total Grease	C Stored
Combusted During Use	5	1
Not Combusted During Use	95	-
Landfilled	85.5	90
Dumped on the ground or in storm sewers	9.5	50
Weighted Average	-	**81.8**

- Not applicable

Having derived separate storage factors for oil and grease, the last step was to estimate the weighted average for lubricants as a whole. No data were found apportioning the mass of lubricants into these two categories, but the U.S. Census Bureau (1999) does maintain records of the value of production of lubricating oils and lubricating greases. Assuming that the mass of lubricants can be allocated according to the proportion of value of production (92 percent oil, 8 percent grease), applying these weights to the storage factors for oils and greases (3 percent and 82 percent) yields an overall storage factor of 9 percent.

Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the lubricants weighted average C storage factor and the quantity of C emitted from lubricants in 2005. The Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for oil and grease variables were assumed to have a moderate variance, in triangular or uniform distribution. Uncertainty estimates for lubricants production were assumed to be rather high (±20 percent). A narrow uniform distribution, with maximum 6% uncertainty around the mean, was applied to the lubricant C content coefficient.

The Monte Carlo analysis, given a 95 percent confidence interval, produced a storage factor distribution that approximates a normal curve, around a mean of 10.2 percent (with individual storage factors for oil and grease at 4 and 64 percent), with a standard deviation of 3.7 percent and 95 percent confidence limits of 3.9 and 17.5 percent. This compares to the calculated estimate, used in the Inventory, of 9.2 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 21.4 Tg CO_2, standard deviation of 1.8, and 95 percent confidence limits of 17.9 and 25.0 Tg CO_2. This compares with a calculated estimate of 21.6 Tg CO_2.

The principal sources of uncertainty for the disposition of lubricants are the estimates of the commercial use, post-use, and environmental fate of lubricants, which, as noted above, are largely based on assumptions and judgment. There is no comprehensive system to track used oil and greases, which makes it difficult to develop a verifiable estimate of the commercial fates of oil and grease. The environmental fate estimates for percent of C stored are less uncertain, but also introduce uncertainty in the estimate.

The assumption that the mass of oil and grease can be divided according to their value also introduces uncertainty. Given the large difference between the storage factors for oil and grease, changes in their share of total lubricant production have a large effect on the weighted storage factor.

Future improvements to the analysis of uncertainty surrounding the lubricants C storage factor and C stored include further refinement of the uncertainty estimates for the individual activity variables.

Waxes

Waxes are organic substances that are solid at ambient temperature, but whose viscosity decreases as temperature increases. Most commercial waxes are produced from petroleum refining, though “mineral” waxes derived from animals, plants, and lignite [coal] are also used. An analysis of wax end uses in the United States, and the fate of C in these uses, suggests that about 42 percent of C in waxes is emitted, and 58 percent is stored.

Methodology and Data Sources

At present, the National Petroleum Refiners Association (NPRA) considers the exact amount of wax consumed each year by end use to be proprietary (Maguire 2004). In general, about thirty percent of the wax consumed each year is used in packaging materials, though this percentage has declined in recent years. The next highest wax end use, and fastest growing end use, is candles, followed by construction materials and firelogs. Table A-23 categorizes some of the wax end uses, which the NPRA generally classifies into cosmetics, plastics, tires and rubber, hot melt (adhesives), chemically modified wax substances, and other miscellaneous wax uses (NPRA 2002)

Table A-66: Emissive and Non-emissive (Storage) Fates of Waxes: Uses by Fate and Percent of Total Mass

Use	Emissive	Non-emissive
Packaging	**6%**	**24%**
Non-packaging	**36%**	**34%**
Candles	18%	2%
Construction Materials	4%	14%
Firelogs	7%	0%
Cosmetics	1%	2%
Plastics	1%	2%
Tires/Rubber	1%	1%
Hot Melts	1%	1%
Chemically Modified	0%	1%
Other	2%	9%
Total	**42%**	**58%**

A C storage factor for each wax end use was estimated and then summed across all end uses to provide an overall C storage factor for wax. Because no specific data on C contents of wax used in each end use were available, all wax products are assumed to have the same C content. **Error! Reference source not found.** categorizes wax end uses identified by the NPRA, and lists each end use's estimated C storage factor.

Table A-67: Wax End-Uses by Fate, Percent of Total Mass, Percent C Stored, and Percent of Total C Mass Stored

Use	Percent of Total Wax Mass	Percent of C Stored	Percent of Total C Mass Stored
Candles	20%	10%	2%
Firelogs	7%	1%	+
Hotmelts	3%	50%	1%
Packaging	30%	79%	24%
Construction Materials	18%	79%	14%
Cosmetics	3%	79%	2%
Plastics	3%	79%	2%
Tires/Rubber	3%	47%	1%
Chemically Modified	1%	79%	1%
Other	12%	79%	9%
Total	**100%**	**NA**	**58%**

+ Does not exceed 0.5 percent
Source, mass percentages: NPRA 2002. Estimates of percent stored are based on professional judgment, ICF Consulting.
Note: Totals may not sum due to independent rounding.

Emissive wax end uses include candles, firelogs (synthetic fireplace logs), hotmelts (adhesives), matches, and explosives. At about 20 percent, candles consume the greatest portion of wax among emissive end uses. As candles combust during use, they release emissions to the atmosphere. For the purposes of the Inventory, it is assumed that 90 percent of C contained in candles is emitted as CO_2. In firelogs, petroleum wax is used as a binder and as a fuel, and is combusted during product use, likely resulting in the emission of nearly all C contained in the product. Similarly, C contained in hotmelts is assumed to be emitted as CO_2 as heat is applied to these products during use. It is estimated that 50 percent of the C contained in hot melts is stored. Together, candles, firelogs, and hotmelts constitute approximately 30 percent of annual wax production (NPRA 2002).

All of the wax utilized in the production of packaging, cosmetics, plastics, tires and rubber, and other products is assumed to remain in the product (i.e., it is assumed that there are no emissions of CO_2 from wax during the production of the product). Wax is used in many different packaging materials including wrappers, cartons, papers, paperboard, and corrugated products (NPRA 2002). Davie (1993) and Davie et al. (1995) suggest that wax coatings in packaging products degrade rapidly in an aerobic environment, producing CO_2; however, because packaging products ultimately enter landfills typically having an anaerobic environment, most of the C from this end use is assumed to be stored in the landfill.

In construction materials, petroleum wax is used as a water repellent on wood-based composite boards, such as particle board (IGI 2002). Wax used for this end-use should follow the life-cycle of the harvested wood used in product, which is classified into one of 21 categories, evaluated by life-cycle, and ultimately assumed to either be disposed of in landfills or be combusted (EPA 2003).

The fate of wax used for packaging, in construction materials, and most remaining end uses is ultimately to enter the municipal solid waste (MSW) stream, where they are either combusted or sent to landfill for disposal. Most of the C contained in these wax products will be stored. It is assumed that approximately 21 percent of the C contained in these products will be emitted through combustion or at landfill. With the exception of tires and rubber, these end uses are assigned a C storage factor of 79 percent.

Waxes used in tires and rubber follow the life cycle of the tire and rubber products. Used tires are ultimately recycled, landfilled, or combusted. The life-cycle of tires is addressed elsewhere in this annex as part of the discussion of rubber products derived from petrochemical feedstocks. For the purposes of the estimation of the C storage factor for waxes, wax contained in tires and rubber products is assigned a C storage factor of 47 percent.

Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the estimates of the wax C storage factor and the quantity of C emitted from wax in 2005. A Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. Uncertainty estimates for wax variables were assumed to have a moderate variance, in normal, uniform, or triangular distribution; uniform distributions were applied to total consumption of waxes and the C content coefficients.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 57.9 percent, with a standard deviation of 6.6 percent and 95 percent confidence limits of 44 percent and 69 percent. This compares to the calculated estimate, used in the Inventory, of 58 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 1.1 Tg CO_2, standard deviation of 0.19 Tg CO_2, and 95 percent confidence limits of 0.72 and 1.48 Tg CO_2. This compares with a calculated estimate of 0.96 Tg CO_2. This value is within the range of 95 percent confidence limits established by this quantitative uncertainty analysis. Uncertainty associated with the wax storage factor is considerable due to several assumptions pertaining to wax imports/exports, consumption, and fates.

Miscellaneous Products

Miscellaneous products are defined by the U.S. Energy Information Administration as: "all finished [petroleum] products not classified elsewhere, e.g., petrolatum; lube refining byproducts (e.g., aromatic extracts and tars); absorption oils; ram-jet fuel; petroleum rocket fuel; synthetic natural gas feedstocks; and specialty oils."

Methodology and Data Sources

Data are not available concerning the distribution of each of the above-listed subcategories within the "miscellaneous products" category. However, based on the anticipated disposition of the products in each subcategory, it is assumed that all of the C content of miscellaneous products is emitted rather than stored. Petrolatum and specialty oils (which include greases) are likely to end up in solid waste or wastewater streams rather than in durable products, and would be emitted through waste treatment. Absorption oil is used in natural gas processing and is not a feedstock for manufacture of durable products Jet fuel and rocket fuel are assumed to be combusted in use, and synthetic natural gas feedstocks are assumed to be converted to synthetic natural gas that is also combusted in use. Lube refining byproducts could potentially be used as feedstocks for manufacture of durable goods, but such byproducts are more likely to be used in emissive uses. Lube refining byproducts and absorption oils are liquids and are would be precluded from disposal in landfills. Because no sequestering end uses of any of the miscellaneous products subcategories have been identified, a zero percent storage factor is assigned to miscellaneous products. According to EIA (2006), the C content of miscellaneous petroleum products in 2005 was approximately 4.7 Tg C.. One hundred percent of the C content is assumed to be emitted to the atmosphere, where it is oxidized to CO_2.

Uncertainty

A separate uncertainty analysis was not conducted for miscellaneous products, though this category was included in the uncertainty analysis of other non-energy uses discussed in the following section.

Other Non-Energy Uses

The remaining fuel types use storage factors that are not based on U.S.-specific analysis. For industrial coking coal and distillate fuel oil, storage factors were taken from IPCC (1997), which in turn draws from Marland and Rotty (1984). For the remaining fuel types (petroleum coke, miscellaneous products, and other petroleum), IPCC does not provide guidance on storage factors, and assumptions were made based on the potential fate of C in the respective NEUs. For all these fuel types, the overall methodology simply involves multiplying C content by a storage factor, yielding an estimate of the mass of C stored. To provide a complete analysis of uncertainty for the entire NEU subcategory, the uncertainty around the estimate of "other" NEUs was characterized, as discussed below.

Uncertainty

A Tier 2 Monte Carlo analysis was performed using @RISK software to determine the level of uncertainty surrounding the weighted average of the remaining fuels' C storage factors and the total quantity of C emitted from these other fuels in 2005. A Tier 2 analysis was performed to allow the specification of probability density functions for key variables, within a computational structure that mirrors the calculation of the Inventory estimate. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for some of the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge. A uniform distribution was applied to coking coal consumption, while the remaining consumption inputs were assumed to be normally distributed. The C content coefficients were assumed to have a uniform distribution; the greatest uncertainty range, 10 percent, was applied to coking coal and miscellaneous products. C coefficients for distillate fuel oil ranged from 19.52 to 20.15 Tg C/QBtu. The fuel-specific storage factors were assigned wide triangular distributions indicating greater uncertainty.

The Monte Carlo analysis produced a storage factor distribution that approximates a normal curve around a mean of 40.6 percent, with a standard deviation of 11.3 percent and 95 percent confidence limits of 20 percent and 64 percent. This compares to the calculated, weighted average (across the various fuels) storage factor of 22 percent. The analysis produced an emission distribution approximating a normal curve with a mean of 28.9 Tg CO_2 and a standard deviation of 5.8 Tg CO_2, and 95 percent confidence limits of 17.3 Tg CO_2 and 40.1 Tg CO_2. This compares with the Inventory estimate of 37.9 Tg CO_2, which falls closer to the upper boundary of the confidence limit. The uncertainty analysis results are driven primarily by the very broad uncertainty inputs for the storage factors.

References

ACC (2006) "Guide to the Business of Chemistry, 2005," American Chemistry Council.

ACC (2005) "Guide to the Business of Chemistry, 2003," American Chemistry Council.

American Gas Association (1974) *Gas Engineer's Handbook,* New York, NY, Industrial Press, pp. 3/71, 3.87.

APC (2006) "APC Year-End Statistics for 2005," April 2006, available online at <http://www.americanplasticscouncil.org/benefits/economic/economic.html>.

APC (2005) "APC Year-End Statistics for 2004," April 2005, available online at <http://www.americanplasticscouncil.org/benefits/economic/economic.html>.

APC (2004) "APC Year-End Statistics for 2003," March 2004, available online at <http://www.americanplasticscouncil.org/benefits/economic/economic.html>.

API (1990 through 2005) *Sales of Natural Gas Liquids and Liquefied Refinery Gases*, American Petroleum Institute.

API (1988) *Alcohols and Ethers: A Technical Assessment of Their Applications as Fuels and Fuel Components*, American Petroleum Institute, API 4261.

Applied Systems Corporation (1976) *Compilation of Oil Shale Test Results,* submitted to the Office of Naval Research, April 1976, p. 3-2.

ASTM (1985) *ASTM and Other Specifications for Petroleum Products and Lubricants,* American Society for Testing and Materials. Philadelphia, PA.

Black, F. and L. High (1979) "Methodology for Determining Particulate and Gaseous Diesel Emissions," in: *The Measurement and Control of Diesel Particulate Emissions,* Society of Automotive Engineers, p. 128.

Boldt, K. and B.R. Hall (1977) *Significance of Tests for Petroleum Products*, Philadelphia, PA, American Society for Testing and Materials, p. 30.

C.R. Martel and L.C. Angello (1977) "Hydrogen Content as a Measure of the Combustion Performance of Hydrocarbon Fuels," in *Current Research in Petroleum Fuels,* Volume I. New York, NY, MSS Information Company, p. 116.

Davie, I.N. (1993) *Compostability of Petroleum Wax-based Coatings*. Technical Association for the Pulp and Paper Industry Journal. Vol. 76 (2) (p. 167–170).

Davie, I. N., Winter, J. P., Varoney, R.P. (1995) D*ecomposition of Coated Papers from a Quick-service Restaurant*. Technical Association for the Pulp and Paper Industry Journal. Vol. 78 (5) (p. 127–130)

DeLuchi (1993) *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,* Volume 2, ANL/ESD/TM-22, Vol. 2. Chicago, IL, Argonne National Laboratory. Appendix C, pp. C-1 to C-8.

DOC (1929) *Thermal Properties of Petroleum Products*, U.S. Department of Commerce, National Bureau of Standards. Washington, DC. pp.16-21.

EIA (1995 through 2006) *Petroleum Supply Annual*, Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA (1993) *Btu Tax on Finished Petroleum Products,* Energy Information Administration, Petroleum Supply Division (unpublished manuscript, April 1993).

EIA (1994) *Emissions of Greenhouse Gases in the United States 1987-1992*, Energy Information Administration, U.S. Department of Energy. Washington, DC. November, 1994. DOE/EIA 0573.

EIA (2001a) *Annual Energy Review 1999.* Energy Information Administration, U.S. Department of Energy, Washington, DC. DOE/EIA-0384(99).

EIA (2001) *Cost and Quality of Fuels for Electric Utility Plants 2000*, Energy Information Administration. Washington, DC. August 2001. Available online at <http://www.eia.doe.gov/cneaf/electricity/cq/cq_sum.html>.

EIA (2002) *Coal Industry Annual,* U.S. Department of Energy, Energy Information Administration. Washington, DC.

EIA (2003) *State Energy Data 2000: Consumption*, U.S. Energy Information Administration, U.S. Department of Energy, Washington, DC. August 2003. Available online at <http://www.eia.doe.gov/emeu/states/_use_multistate.html>.

EIA (2005) *Monthly Energy Review, September 2005 and Unpublished Supplemental Tables on Petroleum Product detail*. Energy Information Administration, U.S. Department of Energy, Washington, DC, DOE/EIA-0035(2005/09).

EIA (2006) *Monthly Energy Review, September 2006* and Unpublished Supplemental Tables on Petroleum Product detail. Energy Information Administration, U.S. Department of Energy, Washington, DC, DOE/EIA-0035(2006/09).

EPA (2000a) *Biennial Reporting System (BRS)*. U.S. Environmental Protection Agency, Envirofacts Warehouse. Washington, DC. Available online at <http://www.epa.gov/enviro/html/brs/>.

EPA (2000b) *Toxics Release Inventory, 1998*. U.S. Environmental Protection Agency, Office of Environmental Information, Office of Information Analysis and Access, Washington, DC. Available online at <http://www.epa.gov/triexplorer/chemical.htm>.

EPA (2004) *Biennial Reporting System (BRS)*. U.S. Environmental Protection Agency, Envirofacts Warehouse. Washington, DC. Available online at <http://www.epa.gov/enviro/html/brs/>.

EPA (2006a) *Air Emissions Trends - Continued Progress Through 2005.* U.S. Environmental Protection Agency, Washington DC. December 19, 2006. < http://www.epa.gov/air/airtrends/index.html>

EPA (2006b) *Biennial Reporting System (BRS) Database*. U.S. Environmental Protection Agency, Envirofacts Warehouse. Washington, DC. Available online at <http://www.epa.gov/enviro/html/brs/>.

FEB, (2005) *Fiber Economics Bureau, as cited in C&EN (2005)* "Production: Growth in Most Regions" Chemical & Engineering News, American Chemical Society, 11 July. Available online at <http://www.cen-online.org>.

Funkenbush, E.F., D.G. Leddy, and J.H. Johnson (1979) "The Organization of the Soluble Organic Fraction of Diesel Particulate Matter," in Society of Automotive Engineers, *The Measurement and Control of Diesel Particulate Emissions*, p. 128.

Gas Technology Institute (1992) Database as documented in W.E. Liss, W.H. Thrasher, G.F. Steinmetz, P. Chowdiah, and A. Atari, *Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States.* GRI-92/0123. March 1992.

Guerra, C.R., K. Kelton, and DC Nielsen (1979) "Natural Gas Supplementation with Refinery Gases and Hydrogen," in Institute of Gas Technology, *New Fuels and Advances in Combustion Technologies*. Chicago, IL, June 1979.

Guthrie, V. (ed.) (1960) *Petroleum Products Handbook*. New York, NY, McGraw-Hill.

Hadaller, O.J. and A.M. Momenthy (1990) *The Characteristics of Future Fuels,* Part 1, "Conventional Heat Fuels". Seattle, WA, Boeing Corp. September 1990. pp. 46-50.

Hare, C.T. and R.L. Bradow (1979) "Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and the Effects of Fuel Composition," in Society of Automotive Engineers, *The Measurement and Control of Diesel Particulate Emissions*, p. 128.

Hare, C.T., K.J. Springer, and R.L. Bradow (1979) "Fuel and Additive Effects on Diesel Particulate-Development and Demonstration of Methodology," in Society of Automotive Engineers, *The Measurement and Control of Diesel Particulate Emissions*, p. 179.

Hong, B.D. and E.R. Slatnick (1994) "Carbon Dioxide Emission Factors for Coal, "U.S. Energy Information Administration, *Quarterly Coal Report*, *January-March 1994*. Washington, DC.

Howard (1993). *Handbook of Environmental Fate and Exposure Data for Organic Chemicals: Vol. II Solvents* 2 Phillip H Howard, Ed. CRC Lewis Publishers, 1993

Hunt, J.M. (1979) Petroleum Geochemistry and Geology. San Francisco, CA. W.H. Freeman and Company. pp. 31-37.

IGI (2002) *100 Industry Applications*. The International Group Inc. Available online at <http://www.igiwax.com/100_apps.shtml>. Toronto, Ontario.

IISRP (2003) "IISRP Forecasts Moderate Growth in North America to 2007" International Institute of Synthetic Rubber Producers, Inc. New Release; available online at: <http://www.iisrp.com/press-releases/2003-Press-Releases/IISRP-NA-Forecast-03-07.html>.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.* Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

James, A. (2000) Personal communication between Suzanne Bratis of ICF International and Alan James of Akzo Nobel Coatings, Inc. July 2000. (Tel: 614-294-3361).

Longwell, J.P. (1991) "Interface Between Fuels and Combustion," in *Fossil Fuel Combustion: A Sourcebook,* New York, NY, John Wiley & Sons.

Maguire, J. (2004) National Petrochemicals and Refiners Association Wax Contact. *Personal Communication* (August – September, 2004)

Martin, S.W. (1960) "Petroleum Coke," in Virgil Guthrie (ed.), *Petroleum Processing Handbook,* New York, NY, McGraw-Hill, pp. 14-15.

Mason, R.L. (1981) "Developing Prediction Equations for Fuels and Lubricants," SAE Paper 811218, p.34. October 1981.

Mosby, F., G.B. Hoekstra, T.A. Kleinhenz, and J.M. Sokra (1976) "Pilot Plant Proves Resid Process," in *Chemistry of Petroleum Processing and Extraction*, MSS Information Corporation, p.227.

National Institute for Petroleum and Energy Research (1990 through 2004) *Motor Gasolines, Summer* and *Motor Gasolines, Winter*.

National Institute for Petroleum and Energy Research (1992) *Fuel Oil Surveys,* Bartlesville, OK.

NPRA (2002) *North American Wax—A Report Card*. Report presented at the National Petrochemicals and Refiners Association Lubricants and Waxes Meeting (11/15/2002). NPRA (LW-02-126). Washington, DC.

Rinehart, T. (2000) Personal communication between Thomas Rinehart of U.S. Environmental Protection Agency, Office of Solid Waste, and Randall Freed of ICF International. July 2000. (Tel: 703-308-4309).

Ringen, S., J. Lanum, and F.P. Miknis (1979) "Calculating Heating Values from the Elemental Composition of Fossil Fuels," *Fuel,* Vol. 58, January 1979, p.69.

RMA (2006). *Scrap Tire Markets in the United States 2005 Edition.* Rubber Manufacturers Association, Washington, DC. November 2006.

Rose, J.W. and J.R. Cooper (1977) *Technical Data on Fuel,* The British National Committee, World Energy Conference, London, England.

SAIC (1992) "Analysis of the Relationship Between Heat and Carbon Content of U.S. Fuels: Final Task Report," Science Applications International Corporation, prepared for the U.S. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternative Fuels. Washington, DC.

SAIC (2005) Analysis prepared by Science Applications International Corporation for EPA, Office of Air and Radiation, Market Policies Branch.

Schneider, S. (2007) E-mail between Shelly Schneider of Franklin Associates (a division of ERG) and Sarah Shapiro of ICF International, January 10, 2007.

U.S. Bureau of the Census (2004) *Soap and Other Detergent Manufacturing: 2002*, Issued December 2004, EC02-31I-325611 (RV). Available online at <http://www.census.gov/prod/ec02/ec0231i325611.pdf>.

U.S. National Research Council (1927) *International Critical Tables of Numerical Data, Physics, Chemistry, and Technology,* New York, NY, McGraw-Hill.

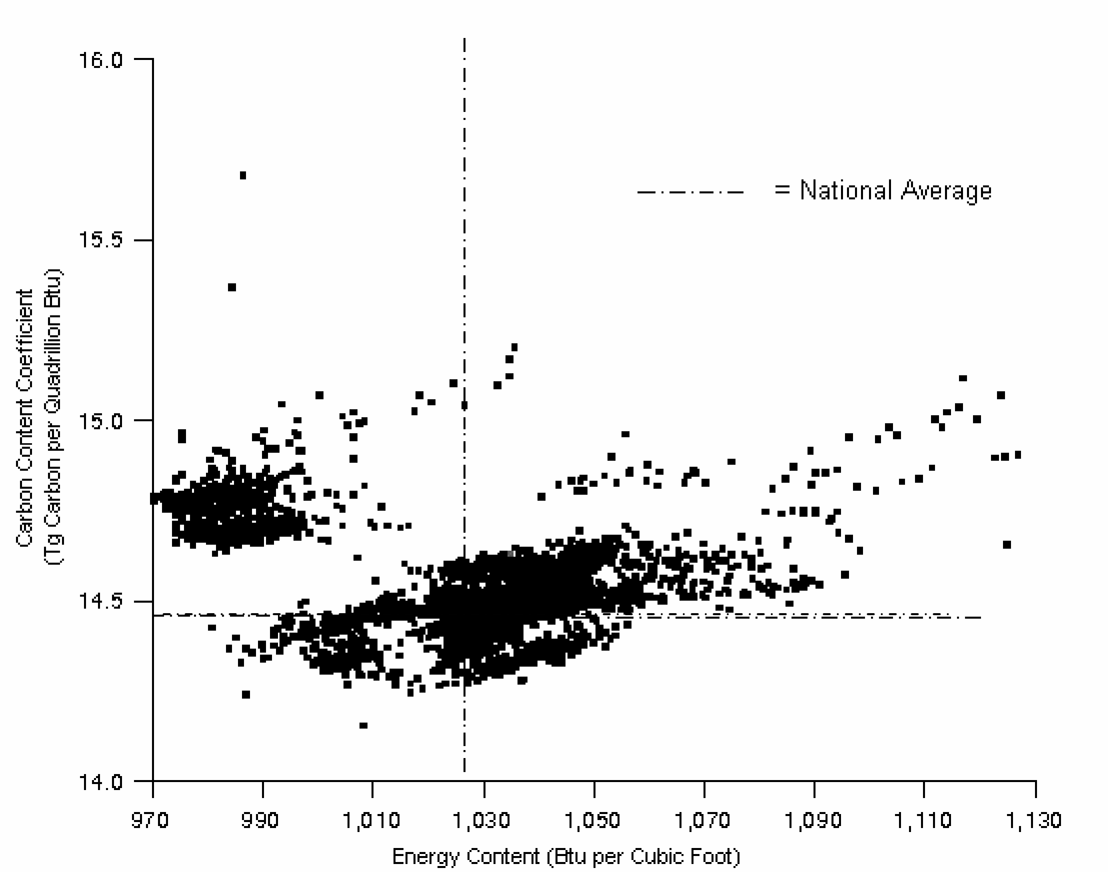
Unzelman, G.H. (1992) "A Sticky Point for Refiners: FCC Gasoline and the Complex Model," *Fuel Reformulation*, July/August 1992, p. 29.

USGS (1998) *CoalQual Database Version 2.0*, U.S. Geological Survey.

Vorum, D.A. (1974) "Fuel and Synthesis Gases from Gaseous and Liquid Hydrocarbons," in American Gas Association, *Gas Engineer's Handbook,* New York, NY, Industrial Press, p. 3/71.

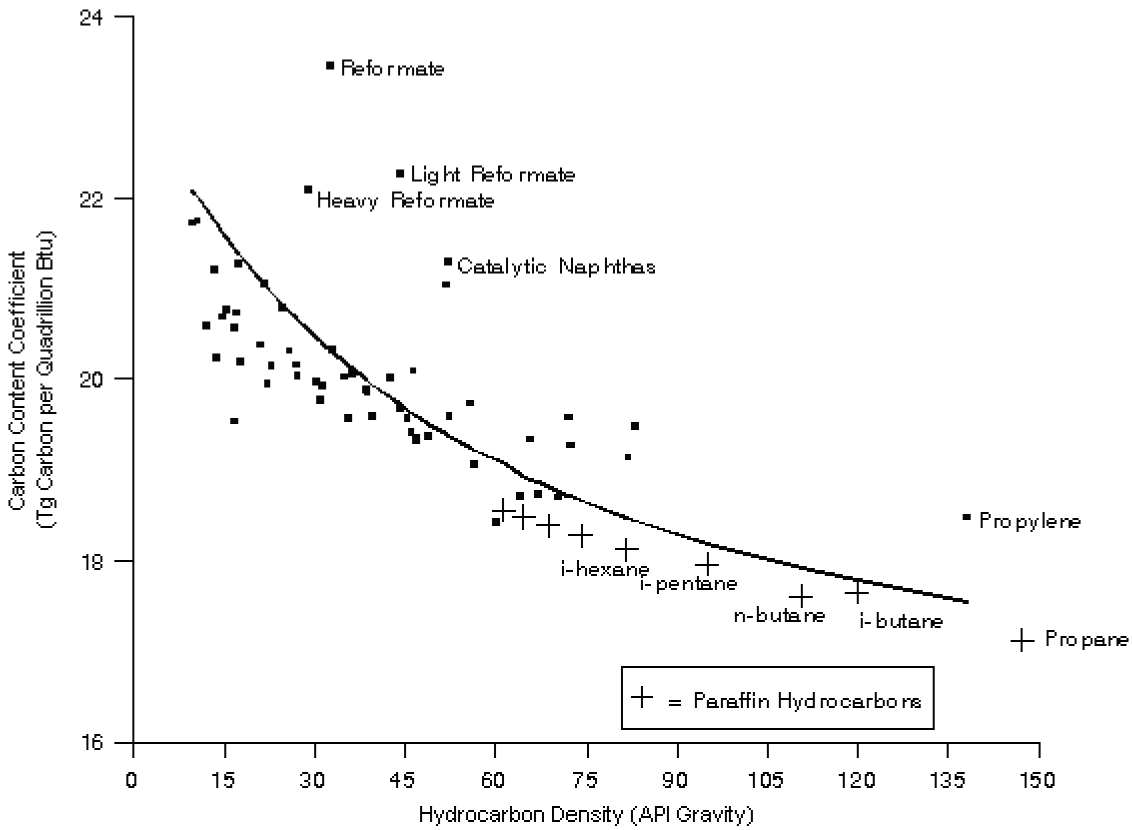
Ward, C.C. (1978) "Petroleum and Other Liquid Fuels," in *Marks' Standard Handbook for Mechanical Engineers,* New York, NY, McGraw-Hill, pp. 7-14.

Figure A-1: Carbon Content for Samples of Pipeline-Quality Natural Gas Included in the Gas Technology Institute Database



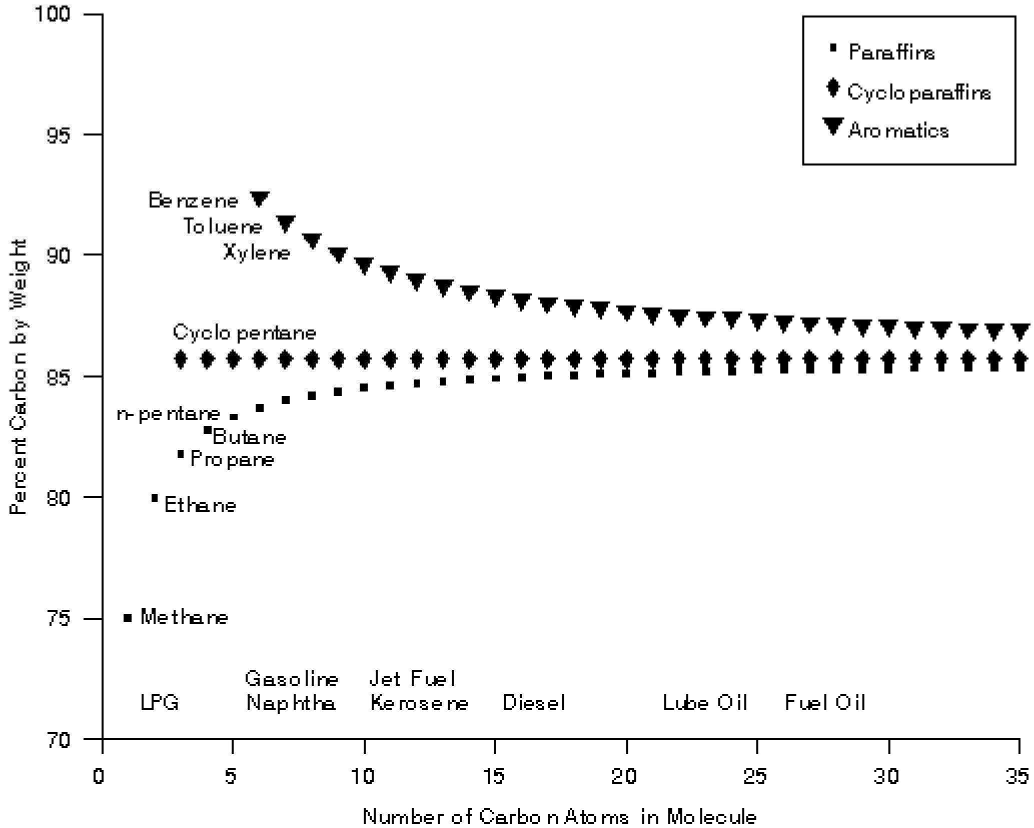
Source: EIA (1994) Energy Information Administration, Emissions of Greenhouse Gases in the United States 1987-1992, U.S. Department of Energy, Washington, DC, November, 1994, DOE/EIA 0573, Appendix A.

Figure A-2: Estimated and Actual Relationships Between Petroleum Carbon Content Coefficients and Hydrocarbon Density



Source: Carbon content factors for paraffins are calculated based on the properties of hydrocarbons in V. Guthrie (ed.), *Petroleum Products Handbook* (New York: McGraw Hill, 1960) p. 33. Carbon content factors from other petroleum products are drawn from sources described below. Relationship between density and emission factors based on the relationship between density and energy content in U.S. Department of Commerce, National Bureau of Standards, *Thermal Properties of Petroleum Products*, Miscellaneous Publication, No. 97 (Washington, D.C., 1929), pp.16-21, and relationship between energy content and fuel composition in S. Ringen, J. Lanum, and F.P. Miknis, "Calculating Heating Values from the Elemental Composition of Fossil Fuels,' *Fuel,* Vol. 58 (January 1979), p.69.

Figure A-3: Carbon Content of Pure Hydrocarbons as a Function of Carbon Number



Source: J.M. Hunt, *Petroleum Geochemistry and Geology* (San Francisco, CA, W.H. Freeman and Company, 1979), pp. 31-37.